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Granitic pegmatites and mineralogical museums in Czech Republic

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On the cover: Smoky quartz and albite from Cyrilov, Bory pegmatite field (Czech Republic). Specimen size 18×15 cm. Photo: Jan Cempírek.

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ACTA Mineralogica Petrographica

Granitic pegmatites and mineralogical museums in Czech Republic

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1. Geological introduction to the area visited

(Milan Novák)

The Bohemian Massif is the easternmost part of the Variscan orogenic belt spanning western and central Europe. The Moldanubian Zone is the most internal part of the orogenic belt. The northern and northwestern parts of the Bohemian Massif belong to the Saxothuringian Zone and Sudetes (Fig. I). The Cadomian crystalline basement, represented chiefly by Brunovistulicum, is exposed on the eastern margin as the Brno Batholith. The Bohemian Massif is comprised of Precambrian and Palaeozoic units and Triassic to Tertiary platform cover (Fig. I).

Attempts at geological divisions of the Moldanubian Zone include lithostratigraphic (Zoubek, 1988), tectonic (Fuchs & Matura, 1976), and terrane (Matte *et al.*, 1990) criteria. The following terranes were defined: 1. Gföhl terrane (unit), named originally as the Gföhl nappe (Fuchs & Matura, 1976; Tollmann, 1982), includes HP granulites associated with pyrope- and spinel-peridotites, pyroxenites, eclogites, leucocratic migmatites, orthogneisses, paragneisses, amphibolites and metagabbros. 2. Drosendorf terrane (Drosendorf nappe in Austria; Tollmann, 1982) includes the Variegated Group and the Monotonous Group (Matte *et al.*, 1990). It comprises meta-greywacke and meta-argillitic gneisses with marbles, calc-silicate gneiss, graphite gneiss, quartzite, amphibolite, and metagabbro layers. The Moldanubian Zone represents a crustal (and upper mantle)

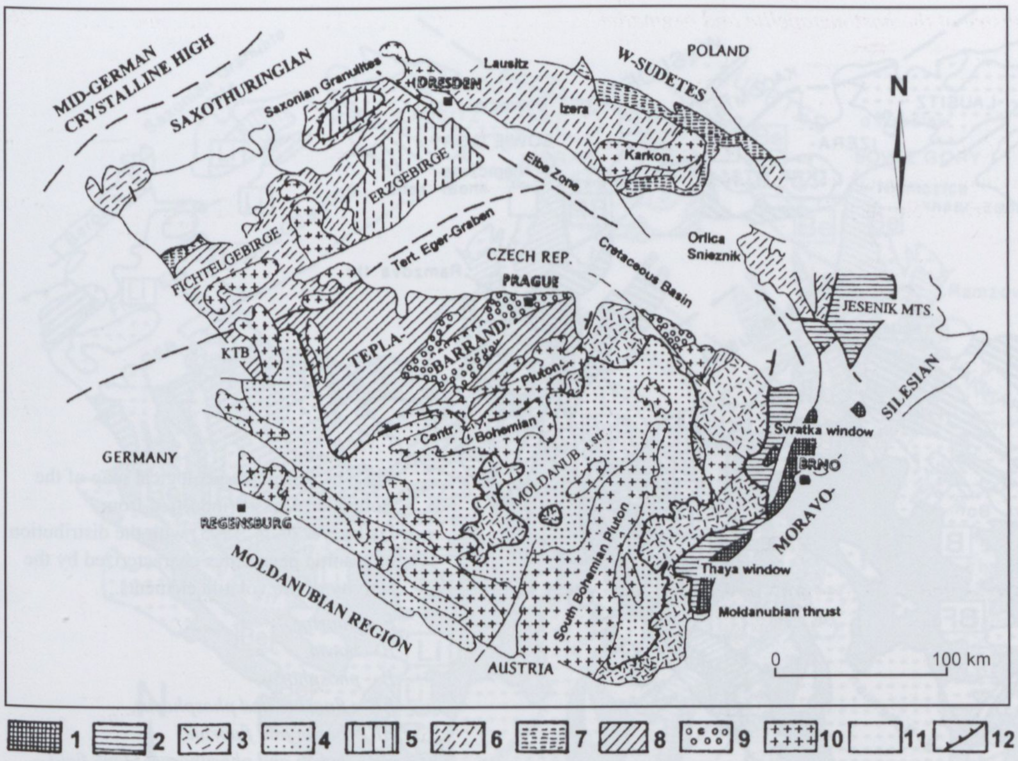


Fig. I. Geological sketch of the Bohemian Massif.
1 – Cadomian granitoids (Brno and Thaya Massifs); 2 – Proterozoic & Palaeozoic, medium-grade (Moravosilesian); 3 – Gföhl unit, medium- to high-grade (Moldanubicum); 4 – Drosendorf unit (= Monotonous and Variegated Groups, Moldanubicum); 5 – high-grade (Saxothuringian); 6 – Proterozoic to Palaeozoic, very low- to medium-grade (Saxothuringian, W-Sudetes); 7 – Palaeozoic, very low- to medium-grade; 8 – mainly Proterozoic, low- to medium-grade, Tepla-Barrandian; 9 – Cambrian to middle Devonian, very low- to low-grade; 10 – late- to post-kinematic Variscan granitoids; 11 – Post-Devonian cover; 12 – thrust or transpressional fault (modified from Dallmeyer et al., 1995).

stack of allochthonous units assembled during the Variscan orogen and modified by several events of superimposed deformation and metamorphic recrystallizations. Three major metamorphic events were recognized: a HT-HP metamorphism developed particularly in granulitic and eclogitic rocks; a HT-MP regional metamorphism (kyanite, staurolite) widespread over many parts of the Moldanubian Zone; evidently later, prograde, major metamorphic events include HT-LP (periplutonic) regional metamorphism (cordierite, andalusite), which accompanied intrusions of late Variscan plutons. Extensional deformations, accompanying collapse of the overthickened crust, took place under amphibolite and locally greenschist facies conditions and may be related to the late HT-LP periplutonic events. These processes are responsible for the uniformity of large areas of gneisses and migmatites in the Moldanubian Zone.

Variscan and less abundant pre-Variscan granitic rocks, highly variable in composition, are widespread all over the region. Isolated bodies of pre-Variscan orthogneiss (tonalite, diorite to tourmaline-muscovite leucogranite) belong to several distinct generations (*cf.* Wendt *et al.*, 1993; Gebauer & Friedl, 1994; Vrána & Kröner, 1995; Breiter *et al.*, 2005a). Five genetic groups of the Variscan granitoids were distinguished by Finger *et al.* (1997): Late Devonian to Early Carboniferous *I*-type granite (~370–340 Ma); Early Carboniferous, deformed *S*-type granite/migmatite (~340 Ma); Late Visean and early Namurian *S*-type and high-K, *I*-type granitoids (~340–310 Ma); Post-collisional epizonal *I*-type granodiorites and tonalites (~320–290 Ma); Late Carboniferous to Permian *A*-type leucogranites (~300–250 Ma).

2. Review of granitic pegmatites in the Moldanubian Zone, Czech Republic

(Milan Novák)

Granitic pegmatites are common in most regional units of the Bohemian Massif, Czech Republic. Pegmatites of distinct classes (see Černý & Ercit, 2005) were recognized in this region: abyssal class (rare in Moldanubian and Saxothuringian Zone), muscovite class (common in Moravo-Silesian Zone), muscovite-rare-element class (common in Teplá-Barrandian Unit of the Moldanubian Zone), rare-element class (the most abundant, common in all regional units) and miarolitic class (common in Sudetes, rare in Moldanubian Zone). Also evident differences were found in chemical composition and mineralogy (activity of volatile components B, F and P; Fig. II, presence of Be-, Li- and REE-bearing minerals; Fig. III). Our field trip involves only granitic pegmatites from the Moldanubian Zone, where pegmatites are the most abundant and most diverse, and where a number of distinct classes, subclasses, types and subtypes (see current classification – Černý & Ercit, 2005) were recognized.

Numerous granitic pegmatites of different origin, class, subclass, type and subtype are widespread throughout the Moldanubian Zone (Fig. IV). They have been object of numerous, mostly mineralogical studies. The following groups (classes) of granitic pegmatites were distinguished and almost all of them also presented during this field trip to illustrate high variability of granitic pegmatites in the Moldanubian Zone within the territory of Czech Republic.

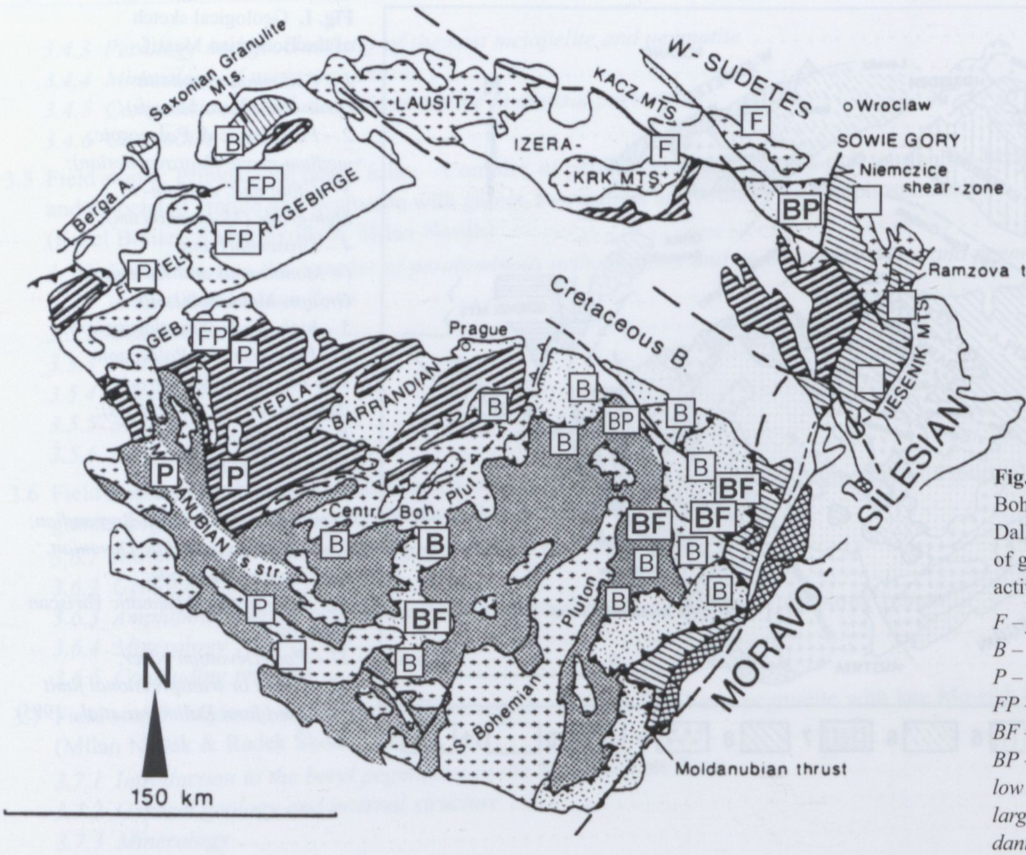


Fig. II. Schematic geological map of the Bohemian Massif (modified from Dallmeyer *et al.*, 1995) with the distribution of granitic pegmatites characterized by the activity of the volatile elements.
F – fluorine,
B – boron,
P – phosphorus,
FP – fluorine and phosphorus,
BF – boron and fluorine,
BP – boron and phosphorus, blank field – low activity of volatile elements, bold text in larger frame – important district with abundant pegmatites (Novák, 2005).

(i) Pegmatites of abyssal class, BBe subclass are typically Al,B-rich with common dumortierite and foitite–olenite. Only several small dikes occur along NE to E border of the Moldanubian Zone. They are evidently related to HP anatectic processes in lower crust as it is indicated by the presence of magmatic kyanite (field stop 4 – Starkoč). A new type of abyssal pegmatites discovered recently is represented by thin vein-cutting granulite containing borosilicates – grandidierite, boralsilite, ominelite, werdingite, dumortierite and tourmaline (field stop 3 – Horní Bory).

(ii) Pegmatites of "subabyssal" class (see Novák, 2005; this class was not defined by Černý & Ercit, 2005) are common in some areas of regional anatexis. They are Al,B-rich, similarly to pegmatites of abyssal class, with common schorl-dravite. Common andalusite and cordierite–sekaninaite suggest MP to LP conditions of upper crust as compared to the abyssal class. Some pegmatites contain pockets lined with large attractive crystals of smoky quartz, tourmalines, apatite, muscovite and feldspars (field stop 3 – Horní Bory).

(iii) Pegmatites of rare element class are the most abundant and exhibit high variability in textural differentiation, degree of fractionation and mineralogy from barren to highly fractionated pegmatites with both LCT (Li-Cs-Ta) and NYF (Nb-Y-F) signature (Černý, 1991a). Most pegmatites of LCT signature are typically B-enriched with tourmaline (schorl, dravite, foitite, elbaite, liddicoatite, rossmanite) as an omnipresent accessory to minor mineral. Less evolved pegmatites are characterized by the presence of dravite-schorl to schorl, locally andalusite and garnet, and also some accessory minerals (field stops 5 – Přibyslavice and 6 – Vlastějovice). A specific type of these pegmaties are highly texturally differentiated bodies with only trace amounts of Li and Be and common primary Fe-Mn phosphates (field stop 5 – Přibyslavice). More fractionated beryl-type pegmatites (field stop 7 – Myšenec) locally with some accessory minerals (beryl, phenakite, danalite, niobian rutile, ilmenite, monazite, xenotime, Y-REE oxide minerals) are less abundant relatively to more evolved complex (Li-bearing) pegmatites, some with a variety of accessory minerals. Lepidolite-subtype pegmatites (field stop 1 – Rožná) predominate over elbaite subtype (field stop 6 – Vlastějovice). Pegmatites of NYF family occur exclusively in the Třebíč and Čertovo břemeno syenite plutons. They vary from primitive allanite-type pegmatites to more evolved pegmatites of euxenite type (field stop 2 – Oslavice; Škoda & Novák, 2007). Role of volatiles and light elements in the rare element pegmatites are characterized as follows: LCT – B > F > P, less commonly F > B > P (Fig. II), and Li > Be (Fig. III); NYF – B > F, P and Be >> Li, generally, activities of volatiles are much lower in NYF pegmatites. Some LCT "stockscheider-type" marginal pegmatites locally with beryl are related to highly evolved granites of the Moldanubian Batholith near Lásenice and Horní Stropnice (e.g, Homolka, Šejby) and show low activities of volatiles P >> B, F and Be >> Li (Breiter, 2002; Cempírek *et al.*, 1999).

(iv) Pegmatites of miarolitic class are very rare and only some intragranitic NYF pegmatites enclosed in the Čertovo břemeno

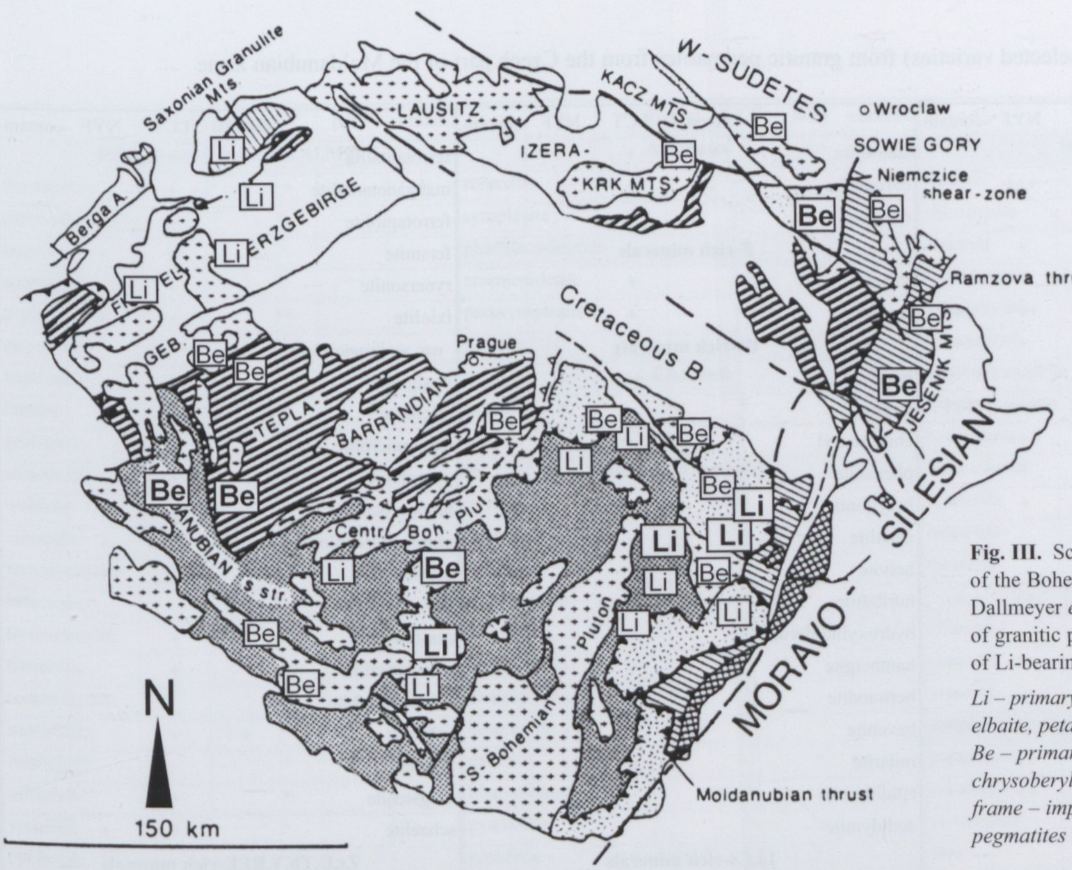


Fig. III. Schematic geological map of the Bohemian Massif (modified from Dallmeyer *et al.*, 1995) with distribution of granitic pegmatites with the dominance of Li-bearing minerals or Be-bearing minerals.

Li – primary Li-bearing minerals (lepidolite, elbaite, petalite, amblygonite–montebrasite), Be – primary Be-bearing minerals (beryl, chrysoberyl, danalite), bold text in larger frame – important district with abundant pegmatites (Novák, 2005).

syenite, central Bohemia, closely related to NYF pegmatites of rare element class show typical features of miarolitic pegmatites – large pockets and close relationship to parental granite.

(v) Pegmatites more or less contaminated from host rocks (*e.g.*, serpentinite, marble, Fe-skarn) are quite abundant in the Moldanubian Zone (Novák, 2007). Contamination is common in some primitive subabyssal pegmatites (field stop 6 – Vlastějovice) and also in more or less fractionated rare element pegmatites (field stop 6 – Vlastějovice).

The pegmatites of rare element class (both LCT and NYF) crystallized in a short period at ~340–335 Ma (Holub *et al.*, 1997a; Novák *et al.*, 1998b; Kotková *et al.*, 2003b; Ertl *et al.*, 2004). Only marginal pegmatites of the Moldanubian Batholith are younger, they are dated at ~319–316 Ma (Breiter & Scharbert, 1998). However, the age of abyssal and subabyssal pegmatites is uncertain. Their relations to regional metamorphism suggest that they are mostly Variscan but some might be pre-Variscan.

The Moldanubian Zone with its pegmatite fields (Fig. IV) represents a characteristic region distinct from the other regional units of the Bohemian Massif. Nevertheless, very similar abyssal pegmatites with dumortierite and tourmaline and rare element pegmatites of lepidolite subtype with lepidolite and elbaite occur in the Saxonian Granulite Massif, Saxothuringian Zone, Germany (Vollstädt & Weiss, 1991). On the other side, famous rare-element tourmaline-poor pegmatites of beryl-columbite-phosphate subtype from Bavaria, Germany (Hagendorf, Zwiesel; Mücke, 2000) dated at ~321 Ma (Chen & Siebel, 2004) have no analogy within the Moldanubian Zone in Czech Republic. However, these pegmatites are very similar to beryl-columbite-phosphate pegmatites in the Domažlice-Poběžovice region (Otov, Meclov) dated at ~480 Ma (Glodny *et al.*, 1998). Very similar granitic pegmatites of lepidolite subtype are known from Maine, New England, USA; they are part of the same Variscan orogenic belt.

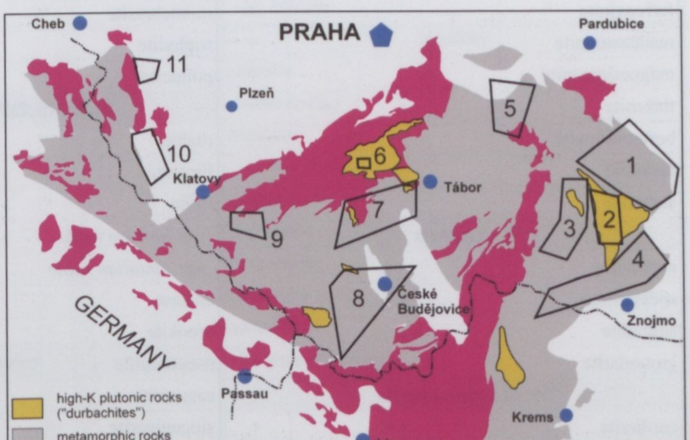


Fig. IV. Schematic geological map of the Modanubian Zone with major pegmatite fields.

1 – Strážek, 2 – Třebíč, 3 – Jihlava, 4 – Vratěnín-Radkovice, 5 – Vlastějovice, 6 – Vepice, 7 – Písek, 8 – South Bohemia, 9 – Sušice, 10 – Domažlice-Poběžovice, 11 – Křiženec.

Table 1. Minerals (including selected varieties) from granitic pegmatites from the Czech part of the Moldanubian Zone

	abyssal	LCT	NYF	contam.
Major minerals				
quartz	+++	+++	+++	+++
var. rose quartz		++		
var. smoky quartz		++	+	+
Feldspars				
albite	++	+++	+++	++
oligoclase	+	+	+	++
andesine				+
orthoclase	+++	+++	+++	++
microcline		+++	+++	+
var. amazonite			+	
var. adularia		+	+	+
hyalophane				+
Micas				
annite	+	++	++	++
siderophyllite				+
phlogopite		+	++	++
muscovite	+	+++	+	+
Tourmalines				
schorl	++	+++	++	++
dravite	+	+	++	++
foitite	+	+		
olenite	+			
uvite				+
Other B-rich minerals				
dumortierite	+	+		+
grandidierite	+			
ominelite	+			
werdingite	+			
boralsilite	+			
danburite				+
datolite				+
ferroaxinite				+
manganaxinite				+
magnesioaxinite				+
tinzenite			+	
boromuscovite		+		
tusionite		+		
sassoline				+
Garnets				
almandine	+	++		
spessartine		++	+	
andradite				++
grossularite				+
Al-rich minerals				
cordierite		++		+
sekaninaite		++		
andalusite		++		
sillimanite	+	+		
kyanite	+			

	abyssal	LCT	NYF	contam.
staurolite	+	+		
corundum	+	+		+
diaspore		+		
F-rich minerals				
topaz		+	+	
fluorite		+	+	+
Be-rich minerals				
beryl		++	+	+
bazzite			+	
chrysoberyl	+			
phenakite		+	+	
beryllonite		+		
danalite		+		
helvite		+		
hurlbutite		+		
hydroxylherderite		+		
hambergite		+	+	
bertrandite		+	+	+
bavenite		+	+	+
milarite		+	+	+
epididymite				+
eudidymite				+
Li,Cs-rich minerals				
petalite		++		
spodumene		+		
elbaite		++	+	+
liddicoatite		+		+
rossmanite		+		
trilithionite		+++	+	+
polylithionite		+	+	+
cookeite		+		
amblygonite		+		
montebrasite		++		
triphylite		+		
pollucite		+		+
Ti,Sn,Nb,Ta,W-rich minerals				
titanite			+	+
ilmenite	+	+	+	
rutile	+	+	+	+
var. niobian rutile	+	+	+	+
var. tantalian rutile		+		+
anatase		+	+	
brookite		+	+	
pseudorutile			+	
cassiterite		+	+	+
zinconigerite		+		
herzenbergite			+	
stokesite		+	+	
ferrocolumbite		+	+	+
manganocolumbite		+	+	

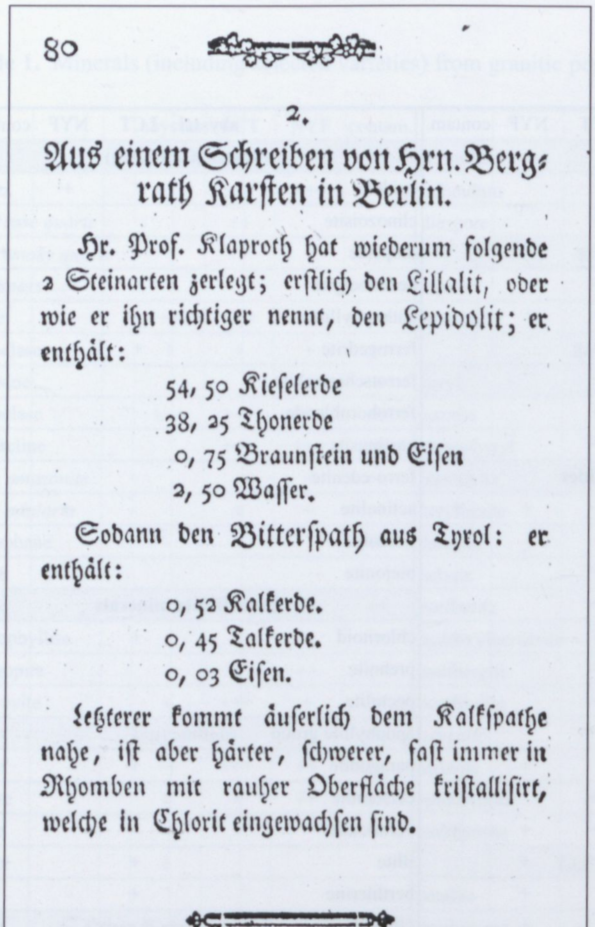
	abyssal	LCT	NYF	contam.
ferrotantalite		+		
manganotantalite		+		
ferrotapiolite		+		
fersmite		+	+	
rynersonite		+		
ixiolite		+	+	
var. wolframoixiolite	+	+		
wodginite		+		
microlite		+		
stibiomicrolite		+		
pyrochlore		+	+	+
uranpyrochlore			+	
plumbopyrochlore			+	
uranbetafite			+	
stibiobetafite				+
cesstibtantite		+		
stibiotantalite		+		
stibiocolumbite				+
ferberite	+	+		
hübnerite				+
tungstenite		+		
scheelite		+	+	+
Zr,U,Th,Y,REE-rich minerals				
zircon	+	+	+	+
uraninite	+	+	+	+
autunite		+		
torbernite		+		
metaautunite		+		
chernikovite		+		
thorite		+		
allanite-(Ce)			+	++
monazite-(Ce)	+	+	+	+
cheralite		+	+	+
xenotime-(Y)	+	+	+	+
aeschynite-(Y)			+	
aeschynite-(Ce)			+	
aeschynite-(Nd)			+	
nioboaeschynite-(Ce)			+	
tantalaeschynite-(Ce)			+	
vigezzite			+	
polycrase-(Y)		+	+	
samarskite-(Y)		+	+	
calciosamarskite			+	
ishikawaite			+	
fergusonite-(Y)		+	+	
yttrobetafite			+	
yttropyrochlore			+	
rhabdophane-(Ce)			+	
bastnaesite-(Ce)			+	+
parisite-(Ce)				+

	abyssal	LCT	NYF	contam.
Phosphates (Ca,Fe,Mn,Al,Mg)				
fluorapatite	+	++	+	+
carbonate-apatite		+		
augelite		+		
scorzalite		+		
triplite		++		
zwieselite		++		
triploidite		+		
beusite		+		
graftonite		++		
sarcopside		+		
wolfeite		+		
alluaudite		+		
ferroalluaudite		+		
heterosite		+		
ferrisicklerite		+		
frondelite		+		
rockbridgeite		+		
mitridatite		+		
fairfieldite		+		
ushkovite		+		
vivianite		+		
cyrilovite		+		
phosphosiderite		+		
strunzite		+		
ludlamite		+		
phosphophyllite		+		
cacoxenite		+		
xanthoxenite		+		
messelite		+		
strengite		+		
harrisonite		+		
jahnsite		+		
benyacarite		+		
natrodufrenite		+		
gayite		+		
earlshannonite		+		
beraunite		+		
melonjosephite		+		
lipscombite		+		
leucophosphite		+		
lacroixite		+		
brasilianite		+		
eosphorite		+		
crandalite		+		
goyazite		+		
gorceixite		+		

	abyssal	LCT	NYF	contam.
Arsenates				
scorodite		+		
symplesite		+		
pharmacosiderite		+		
arseniosiderite		+		
parasymplesite		+		
pitticite		+		
Elements				
graphite	+	+		
bismut		+		
Sulphides, arsenides				
pyrite	+	+	+	+
arsenopyrite	+	+		
löllingite	+	+		
molybdenite		+		
sphalerite		+		+
greenockite		+		
chalcopyrite		+		+
bournonite		+		
galenite			+	
bismuthinite		+		
pyrrhotite		+	+	+
parkerite			+	
pentlandite			+	
argentopentlandite			+	
Oxides, hydroxides				
magnetite		+		+
chromite		+		
gahnite		+		
hercynite	+			
hematite		+		
goethite		+	+	+
psilomelane		+		+
quartz *var. chalcedony*		+		+
opal		+		+
Carbonates				
calcite		+	+	+
siderite		+		
dolomite		+		+
rhodochrosite		+		
aragonite				+
hydrotalcite				+
bismutite		+		
Sulphates				
halotrichite		+		
gypsum		+		
plumbojarosite		+		

	abyssal	LCT	NYF	contam.
Silicates (Ca,Fe,Mg)				
epidote			+	+
clinozoisite				+
diopside				++
hedenbergite				+
anthophyllite				+
ferrogedrite		+		
ferrotschermakite				+
ferrohornblende				+
hastingsite				++
ferro-edenite				+
actinolite			+	+
tremolite				+
mejonite				++
Late silicate minerals				
chloritoid		+		
prehnite				+
pectolite				+
apophyllite group				+
paragonite		+		
celadonite				+
vermiculite				+
illite		+		+
berthierine		+		+
clinochlore			+	+
chamosite		+		+
nontronite		+		+
kaolinite	+	+	+	
montmorillonite		+	+	+
saponite				+
pyrophyllite		+		
talc				+
var. kerolite				+
Zeolites				
natrolite				+
chabazite-(K)				+
analcime		+		+
var. Cs-analcime		+		+
stilbite group				+
laumontite		+		+
thomsonite				+
phillipsite group				+
harmotome				+
clinoptilolite group		+		

Symbols: +++ abundant ++ common + rare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2.

Aus einem Schreiben von Hrn. Berg-
rath Karsten in Berlin.

Hr. Prof. Klaproth hat wiederum folgende 2 Steinarten zerlegt; erstlich den Lillalit, oder wie er ihn richtiger nennt, den Lepidolit; er enthält:

54, 50 Kieselerde
38, 25 Thonerde
0, 75 Braunstein und Eisen
2, 50 Wasser.

Sodann den Bitterspath aus Tyrol: er enthält:

0, 52 Kalkerde.
0, 45 Talkerde.
0, 03 Eisen.

Letzterer kommt äuserlich dem Kalkspathe nahe, ist aber härter, schwerer, fast immer in Rhomben mit rauher Oberfläche kristallisirt, welche in Chlorit eingewachsen sind.

Fig. V. Karsten's letter (1792) containing Klaproth's analytical results and the lepidolite name given by Klaproth to the mineral from Rožná.

Granitic pegmatites and their minerals from the Bohemian Massif and particularly from the Moldanubian Zone have been studied since the second half of 18th century and samples of minerals from granitic pegmatites were obtained by mineralogical collections even earlier. The very first descriptions of minerals were published from the pegmatite Rožná-Hradisko including discovery of a new mineral – lepidolite (Klaproth in Karsten, 1792; Fig. V). Granitic pegmatites of the Písek region, southern Bohemia with beryl and its common alteration product bertrandite, were studied in several papers by Vrba (1888, 1894; Fig. VI). In the same time Scharizer (1888, 1889) recognized geochemical zoning of pegmatites on compositional evolution of micas and tourmalines from a lepidolite pegmatite near Sušice, western Bohemia. Numerous papers were published during 20th century focusing almost exclusively on individual minerals and mineral assemblages; the most important papers of the first half of 20th century includes *e.g.*, Sekanina (1928) – review of the Moravian pegmatites (Fig. VI). Numerous papers were published chiefly from 1960s up to now. Descriptions of the new minerals from granitic pegmatites (Fig. VII) involve, along with already mentioned lepidolite (Klaproth in Karsten, 1792; Černý *et al.*, 1995b), also cyrilovite $NaFe^{3+}_3(PO_4)_2(OH)_4 \cdot 2H_2O$ (Novotný & Staněk, 1953; Novák *et al.*, 2000; Cooper *et al.*, 2000), sekaninaite $Fe^{2+}_2Al_4Si_5O_{18}$ (Staněk & Miškovský, 1975; Černý *et al.*, 1997), stibiobetafite $(Ca,Sb)_2(Ti,Nb,Ta)_2O_6(O,OH,F)$ (Černý *et al.*, 1979) and rossmanite $\square LiAl_2Al_6Si_6O_{18}(BO_3)_3(OH)_4$ (Selway *et al.*, 1998, 1999).

Large number of papers is dealing with crystal chemistry and compositional evolution of the individual minerals: tourmalines (*e.g.*, Povondra, 1981; Povondra *et al.*, 1985; Novák & Povondra, 1995; Novák *et al.*, 1999c, 2004b; Novák & Taylor, 2000; Selway *et al.*, 1998, 1999; Ertl *et al.*, 2004; Cempírek *et al.*, 2006; Buriánek & Novák, 2007); Nb-Ta-Sn-Ti-W oxide minerals (*e.g.*, Černý & Němec, 1995; Novák & Černý, 1998; Novák & Šrein, 1998; Novák *et al.*, 2004a, 2008; Škoda & Novák, 2007); micas (*e.g.*, Černý *et al.*, 1995; Liang *et al.*, 1995; Novák *et al.*, 1999a); sekaninaite (Černý *et al.*, 1997); garnet (Breiter *et al.*, 2005b); borates (Burns *et al.*, 1996; Novák *et al.*, 1998a; Novák 1999). List of all minerals described up to date from granitic pegmatites in the Moldanubian Zone is given in Table 1.

Also several field trips associated with international conferences were organized on granitic pegmatites of the Moldanubian Zone (Lepidolite 200 – 1992; Tourmaline 1997; Phosporus in granites 1998; LERM 2003). In the recent classification of granitic pegmatites (Černý & Ercit, 2005), the following pegmatites and pegmatite districts were mentioned as typical examples of relevant subclasses and subtypes: abyssal class, AB-BBe subclass – Kutná Hora (Field stop 4 Starkoč); rare-element class, REE-Li subclass, beryl-columbite-phosphate subtype – Hagendorf-Süd, Germany; rare-element class, REE-Li subclass, lepidolite subtype – Rožná (Field stop 1);

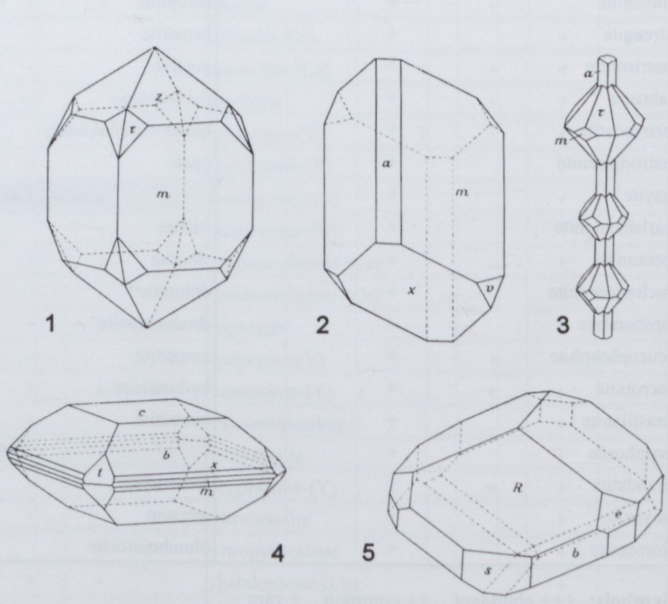

Fig. VI. Crystals of selected minerals from granitic pegmatites of the Moldanubian Zone.

1 – xenotime from Sušice (Scharizer, 1888), 2 – monazite from Dolní Bory (Sekanina, 1933), 3 – oriented intergrowth of zircon and xenotime from Drahonín (Černý, 1956), 4 – cyrilovite from Cyrilov (Strunz, 1956), 5 – tourmaline from Cyrilov (Slavík, 1904).

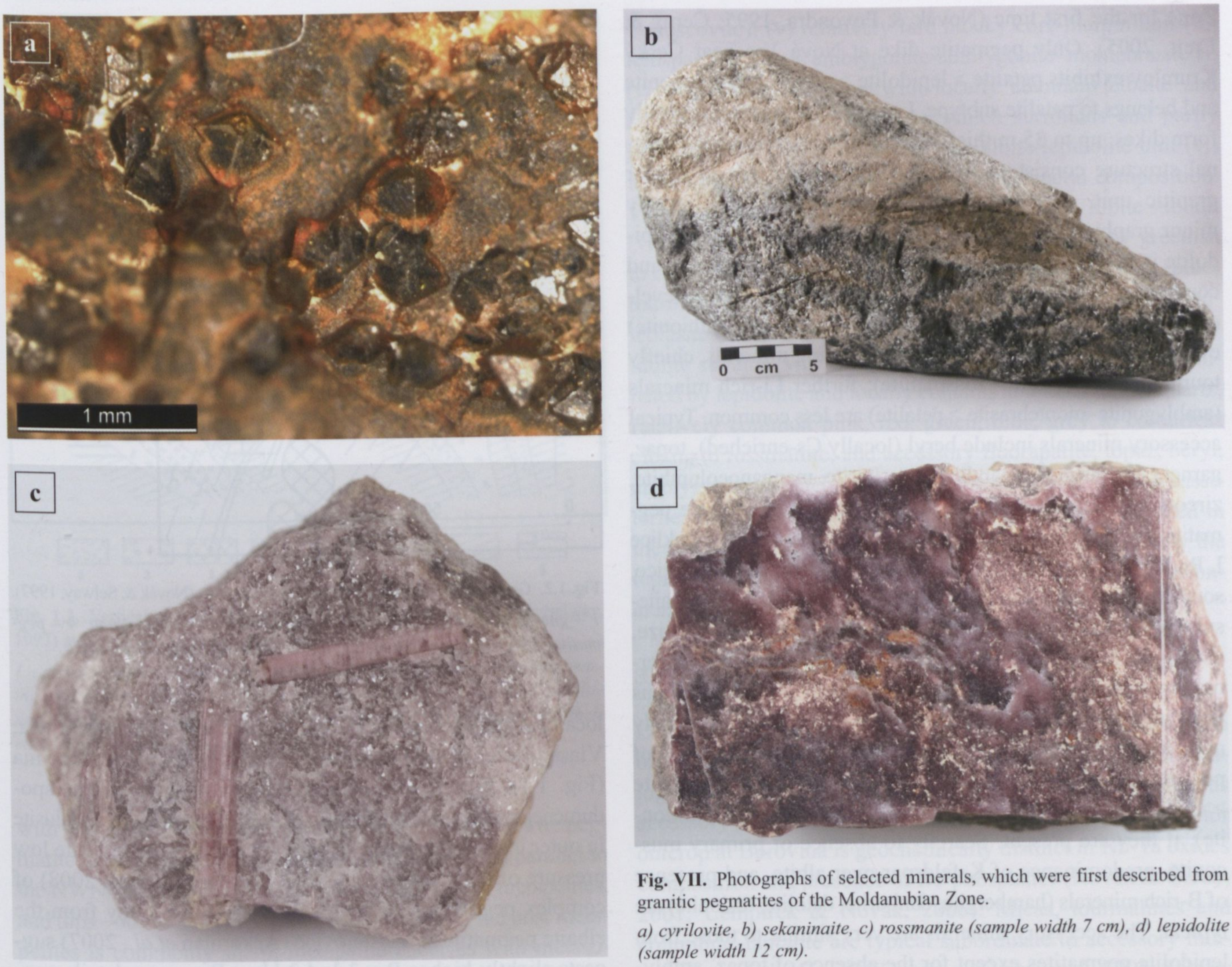

Fig. VII. Photographs of selected minerals, which were first described from granitic pegmatites of the Moldanubian Zone.

a) cyrilovite, b) sekaninaite, c) rossmanite (sample width 7 cm), d) lepidolite (sample width 12 cm).

rare-element class, REE-Li subclass, elbaite subtype – western Moravia (Field stop 6 – Vlastějovice).

An important part of this field trip is a presentation of some mineralogical exhibitions from museums in Czech Republic, where minerals from granitic pegmatites also are presented. Mining and associated collecting of minerals have an old tradition in our country and the oldest mineral collections come from the beginning of 18th century. We will visit mineralogical exhibitions varying from the world-class quality and dimension (National Museum, Prague) to local but interesting exhibitions (*e.g.* Prácheň Museum, Písek, Southern Bohemia; Mining Museum Příbram, Central Bohemia).

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3. Field stops

3.1 Field stop 1: Rožná near Bystřice nad Pernštejnem, Hradisko hill – Classic locality of lepidolite pegmatite, type locality of lepidolite and rossmanite

(Milan Novák & Jan Cempírek)

3.1.1 Introduction to complex pegmatites in the Moldanubian Zone

Complex (Li-bearing) pegmatites of rare-element class are typical in the Moldanubian Zone and currently about 70 individual dikes varying in size from small (~1 m thick) to large (up to 35 m thick) are known in this region (Fig. 1.1). Lepidolite-subtype pegmatites predominate over elbaite-subtype pegmatites, which were defined as a new subtype from the Moldanubian

Zone for the first time (Novák & Povondra, 1995; Černý & Ercit, 2005). Only pegmatite dike at Nová Ves near Český Krumlov exhibits petalite > lepidolite > elbaite > amblygonite and belongs to petalite subtype. Lepidolite pegmatites typically form dikes, up to 35 m thick, with symmetrically zoned internal structure consisting from the contact inwards of border granitic unit, coarse-grained albite-muscovite unit, mostly minor graphic unit evolving to blocky K-feldspar, albite-lepidolite unit with large masses of monomineralic lepidolite and common elbaite. Volumetrically important quartz core is developed only scarcely. Lithium micas (trilithionite > polylithionite) evidently predominate over other Li-bearing minerals, chiefly tourmalines (elbaite >> rossmanite); further Li-rich minerals (amblygonite–montebrasite > petalite) are less common. Typical accessory minerals include beryl (locally Cs-enriched), topaz, garnet (spessartine–almandine), cassiterite, manganocolumbite, zircon, apatite, and pollucite. Typical lepidolite-subtype pegmatites include the localities Rožná, Dobrá Voda, Jeclov, Puklice I, Radkovice, Drahonín, all from western Moravia, Chvalovice, southern Bohemia, Sušice I, western Bohemia (Fig. 1.1). Elbaite-subtype pegmatites differ from lepidolite pegmatites by size, usually form small bodies, up to 5 m thick, and simpler internal structure varying from simply zoned to subhomogeneous with increasing grain size inwards. Graphic unit is locally quite abundant, but quartz core is absent. Also the presence of pockets is typical. Abundant Li-bearing tourmalines (elbaite >> liddicoatite) predominate over lithium micas (polylithionite), if they are present. Scarcity to absence of primary muscovite, predominance of K-feldspar over albite, and presence of B-rich minerals (hambergite, danburite, datolite, tusionite) are typical. The accessory minerals are very similar to those from lepidolite pegmatites except for the absence of topaz, amblygonite–montebrasite and petalite. Typical elbaite-subtype

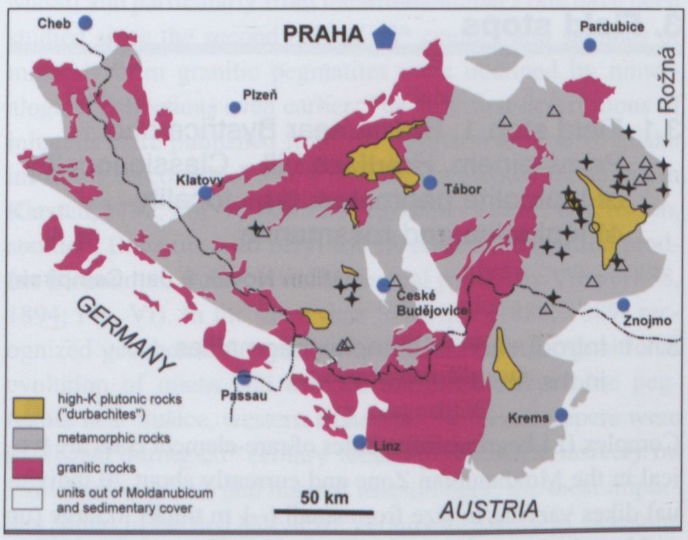


Fig. 1.1. Schematic geological map of the Moldanubian Zone with major occurrences of complex, Li-bearing pegmatites.
Stars – lepidolite subtype pegmatites, triangles – elbaite subtype pegmatites, circle – "mixed family" masutomilite pegmatite.

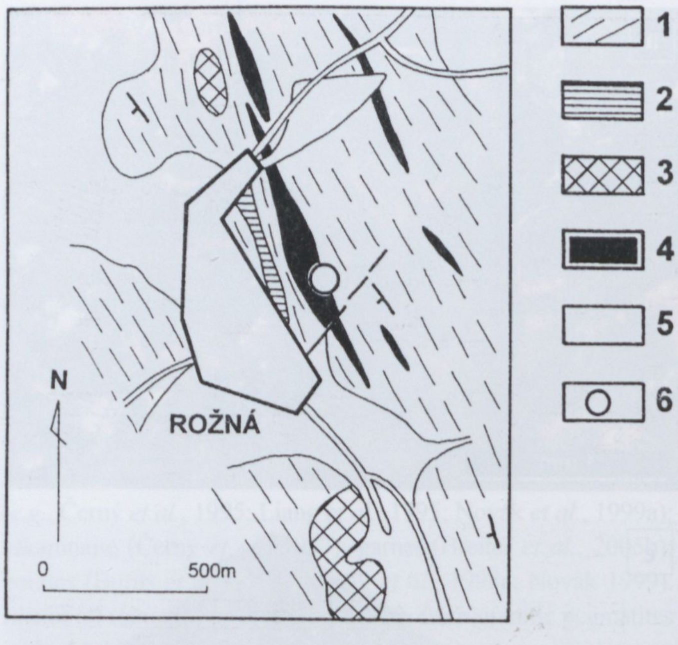


Fig. 1.2. Geological sketch of the Rožná pegmatite area (Novák & Selway, 1997).
1 – gneiss, in part migmatized; 2 – amphibolite; 3 – serpentinite; 4 – pegmatite; 5 – Quaternary sediments; 6 – field trip stop (Hradisko hill).

localities include Řečice, Pikárec, Ctidružice, western Moravia; Vlastějovice, central Bohemia; Bližná I, southern Bohemia (Fig. 1.1). Presence of petalite (and subsolidus quartz+spodumene aggregates after petalite) as well as presence of andalusite in outer units and absence of primary spodumene indicate low pressure of emplacement (< 2.5–3 kbar, see London, 2008) of complex pegmatites, although fluid inclusion study from the elbaite pegmatite at Vlastějovice (Ackerman *et al.*, 2007) suggests slightly higher $P = 3.1–4.3$ kbar. For more details concerning geological position of complex pegmatites, their mineralogy, and internal structure see *e.g.*, Novák & Povondra (1995), Selway *et al.* (1999), Novák *et al.* (1999a).

The Rožná pegmatite is a classic locality of lepidolite-subtype pegmatites of the Moldanubian Zone. It has been frequently mined and studied since the second half of the 18th century; two new mineral species – lepidolite (Klaproth in Karsten, 1792) and rossmanite (Selway *et al.*, 1998) were described from this locality. Compositional evolution of micas and tourmalines as well as columbite-group minerals indicating late stage enrichment in Fe is discussed. Its internal structure, petrography and mineralogy were studied in detail by many authors (*e.g.*, Sekanina, 1946; Černý *et al.*, 1995; Selway *et al.*, 1998, 1999; Němec, 1998; Novák & Černý, 2001; Cempírek & Novák, 2006a); a review of papers dealing with mineralogy including historical papers was presented by Novák *et al.* (1998c).

3.1.2 Geology

The dike of the lepidolite pegmatite is located along the contact of the Strážek Moldanubicum and the Svratka Unit (Fig. 1.2) and dominantly hosted by leucocratic biotite paragneiss

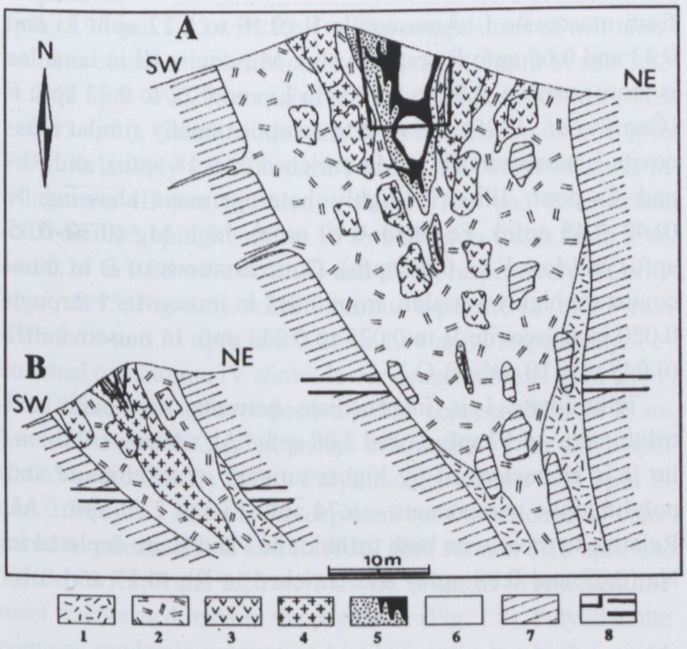


Fig. 1.3. Vertical sections through the Rožná pegmatite (Novák & Selway, 1997) at Hradisko (A) and Borovina (B) hills.

1 – coarse-grained biotite-bearing unit, 2 – coarse-grained tourmaline-bearing unit, graphic unit, 3 – graphic unit, 4 – granitic unit, 5 – albite-lepidolite unit (black – lepidolite subunit), 6 – quartz core, 7 – host rocks and their enclaves, 8 – mining (galleries and quarries).

with widespread intercalations of hornblende gneiss. The pegmatite dike, ~1 km long and ~35 m wide, is oriented parallel to the NWN-trending strike of the foliation of the host metapelites, and dips ~60° WSW (Fig. 1.3). The contact with the host metapelites is commonly sharp; metapelite enclaves with metasomatic tourmaline (dravite – elbaite – schorl, Novák & Selway, 1997) are located in the upper part of the dike. The Rožná pegmatite was mined particularly in an old quarry on the Hradisko hill, where the most differentiated and fractionated central part of the dike is exposed with famous massive aggregates of purple lepidolite. The second exposure at less evolved Borovina hill with rare Be-bearing minerals (beryllonite, hydroxylherderite, hurlbutite, bertrandite; Cempírek & Novák, 2006a) may represent a different erosion level of the dike or a part of the body with rather distinct textural and geochemical evolution (Novák & Černý, 2001).

3.1.3 Internal structure

The almost symmetrically zoned internal structure of the Rožná-Hradisko pegmatite consists of the following textural-paragenetic units (Fig. 1.3): (i) very rare, coarse-grained wall unit (quartz + K-feldspar + plagioclase ± biotite); (ii) abundant, coarse-grained intermediate unit (quartz + K-feldspar + plagioclase + schorl + muscovite), locally with blocks of (iii) graphic unit (K-feldspar + quartz + albite + plumose muscovite + schorl) and masses (or veins?) of (iv) fine- to medium-grained granitic unit (quartz + K-feldspar + albite + schorl + muscovite); (v) relatively rare blocky core-margin unit (K-feldspar + quartz ± amblygonite-amblygonite–montebrasite I); (vi) albite-lepidolite unit with locally abundant elbaite and rare amblygonite–montebrasite, which surrounds and partly penetrates the (vii) quartz core. The albite-lepidolite unit (vi) is very heterogeneous in its texture and mineral composition. The outer part of the albite-lepidolite unit (vi) – albite subunit (via), is dominated by albite and is characterized by greenish to colourless muscovite to Li-muscovite, black to green (blue) tourmaline, cassiterite, fluorapatite and rare amblygonite–montebrasite II. The inner part of the albite-lepidolite unit (via), lepidolite subunit (vib) is adjacent to the quartz core. It is dominated by lepidolite and locally contains abundant albite, quartz, relatively common pink, red, green, blue, grey to colourless elbaite to rossmanite, and accessory fluorapatite, topaz, beryl, amblygonite–montebrasite III, manganocolumbite and cassiterite. Currently, all textural-paragenetic units are exposed in the old quarry except the albite-lepidolite unit and chiefly the lepidolite subunit, which are accessible only during occasional excavations.

3.1.4 Mineralogy

Lepidolite pegmatite at Rožná-Hradisko and its minerals have been studied for a long time including morphological crystallography (Fig. 1.4). It contains several minor and numerous accessory minerals ranging from common to very rare. Minor outcrop at Borovina is geochemically distinct in Nb-Ta oxides composition and presence of Be-phosphates (Novák & Černý, 2001; Cempírek & Novák, 2006). Micas, tourmalines and columbite–tantalite are typical subordinate to accessory minerals both studied in detail (see *e.g.*, Černý *et al.*, 1995; Selway *et al.*, 1999; Novák & Černý, 2001) besides numerous minor to accessory minerals given below.

3.1.4.1 Micas

Disregarding very rare and strongly chloritized **biotite** found exceptionally close to the contact with host rocks, several types of **muscovite**, lepidolite (**trilithionite** to **polylithionite**; Černý *et al.*, 1995) and primary (?) clay minerals (**illite**, **kaolinite**) were recognized based on their position in the pegmatite dike, mineral assemblage and chemical composition. Micas, namely lepidolite, were studied by many authors (see *e.g.*, Wise, 1995; Černý *et al.*, 1995 and references therein).

Silvery, plumose **muscovite I** typically occurs in the graphic unit as muscovite-quartz aggregates, up to 8 cm large. **Muscovite II** forms greenish to yellowish courved flakes, 5 to 20 mm in size, in the albite subunit (via). It is associated with black to green tourmaline and cassiterite. Microscopic **muscovite III** occurs locally as thin lamellae in various types of lepidolite. Late **muscovite IV** forms massive, pale green aggregates in the quartz core locally associated with green trilithionite IV and clay minerals.

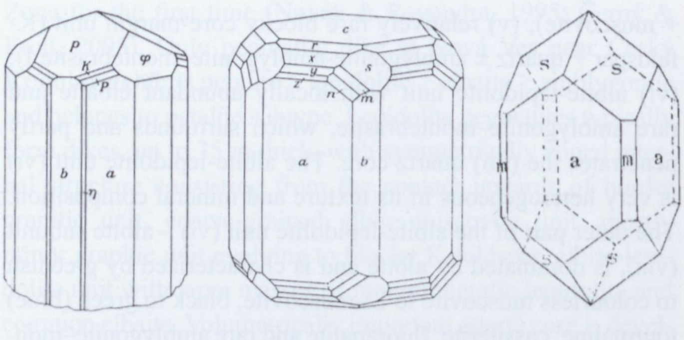


Fig. 1.4. Crystals of selected minerals (elbaite, apatite, cassiterite) from the Rožná pegmatite (Sekanina, 1928).

Trilithionite I occurs in the outer part of the lepidolite subunit as pale pink to purple courved flakes, 1 to 3 cm in size, locally associated with pink elbaite. Brownish to typically purple **trilithionite II** forms massive aggregates of small flakes, 0.5 to 4 mm in size, commonly monomineralic, up to 1 m^3 in volume. It sporadically contains columnar crystals of pale pink rossmanite to elbaite, albite and quartz. **Trilithionite III** is commonly fine-flaked, with flakes 0.5 to 2 mm in size, varying in colour from pale purple to pale green. It also forms massive aggregates, up to several dm^3 in size. Trilithionite III is associated with multicoloured elbaite, quartz, albite, rare manganocolumbite, amblygonite–montebrasite III and/or topaz. **Trilithionite IV** is similar to trilithionite III and differs in green colour. It represents the latest generation of lepidolite and is typically adjacent to the central quartz core. **Polylithionite** is very rare, true polylithionite was found as massive purple mica similar to trilithionite II, but some compositions of grey trilithionite III approach polylithionite as well.

Clay minerals mentioned in this text involve only those occurring in the quartz core closely associated with green trilithionite IV and muscovite IV; secondary clay minerals after amblygonite–montebrasite or replacing quartz along tectonic fractures are not involved. Clay minerals form nodular to irregular very fine-grained aggregates varying from dark dirty green **illite** (centre) to chalky white **kaolinite** (rims). These aggregates are heterogeneous and relationship of all minerals is unclear. Moreover, secondary origin of at least some minerals, chiefly kaolinite, is likely. However, the precursor is not known and closely associated feldspars as well as amblygonite–montebrasite IV are fresh. The sequence of crystallization of the individual micas is: muscovite I → muscovite II → trilithionite I → trilithionite II → trilithionite III → trilithionite IV → muscovite IV → illite. Muscovite III occurs as lamellae in several types of trilithionite, and trilithionite II and III locally attain polylithionite composition (Fig. 1.5).

Muscovite I and muscovite II are close to the end-member composition, but they are slightly Fe- and Na-enriched (0.26 and 0.20 apfu Fe, and 0.20 and 0.18 apfu Na; Fig. 1.5). Muscovite III is heterogeneous, varying in Fe (0.00 to 0.07 apfu), Mg (0.00 to 0.30 apfu), Na (0.01 to 0.10 apfu) and Rb (≤ 0.04 apfu) (Černý *et al.*, 1995). Concentrations of Li and F increase from muscovite I to muscovite II (0.10 to 0.22 apfu Li and 0.33 and 0.66 apfu F, respectively). Muscovite III in lamellae is more variable, 0.00 to 0.10 apfu Li and 0.27 to 0.73 apfu F (Černý *et al.*, 1995). Relative to compositionally similar muscovite I, muscovite IV is Mg-enriched (≤ 0.18 apfu), and Rb- and Cs-poor. Illite is highly heterogeneous showing K (0.42–0.45 apfu), Fe (0.11–0.19 apfu), high Mg (0.30–0.35 apfu) and low F (≤ 0.04 apfu). Concentrations of B in muscovite are highly variable, from 0.011 in muscovite I through 0.020 in muscovite II to 0.023 to 0.253 apfu in muscovite III (0.048 to 1.10 wt% B_2O_3).

Trilithionite I is intermediate between muscovite and trilithionite – 6.57 apfu Si and 3.08 apfu ^{Y}Al, whereas trilithionite II is characterized by higher amount of trilithionite and polylithionite components – 6.74 apfu Si and 2.77 apfu ^{Y}Al. Relative to muscovite both trilithionite I and II are depleted in Na (0.09 and 0.08 apfu) and enriched in Rb (0.17 and 0.16

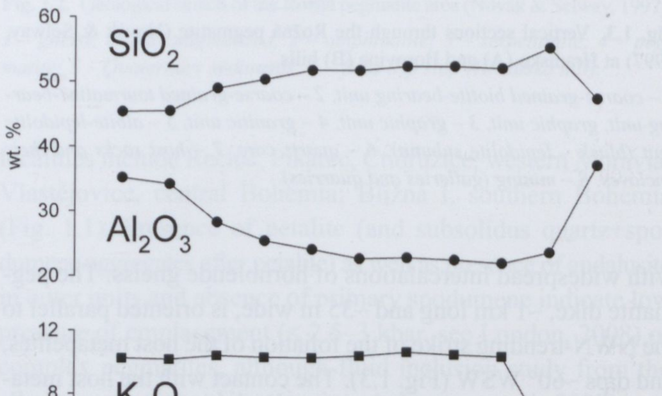


Fig. 1.5. Compositional evolution of phyllosilicates across the Rožná pegmatite. *B – muscovite from graphic unit; D – muscovite from albite subunit, E, F – lepidolite (trilithionite) from the albite subunit (purple); H1-H5 lepidolite (trilithionite–polylithionite) in the lepidolite subunit (purple, white, green); I – illite; S – smectite from quartz core (modified after Černý et al. 1995).*

apfu; 1.93 and 1.82 wt% Rb_2O). The composition of trilithionite III is closer to polylithionite (6.87 to 7.10 apfu Si and 2.53 to 2.67 apfu ${}^{Y}Al$). It contains moderate amounts of Mn (0.05 to 0.07 apfu). Green trilithionite IV is Fe-rich (up to 0.31 apfu Fe^{2+}). Relatively to trilithionite I and II, all colour varieties of trilithionite III and trilithionite IV are Rb- and Cs-enriched (0.01 to 0.05 apfu Rb and 0.16 to 0.08 apfu Cs; 0.86 to 2.05 and 0.24 to 0.88 wt% of Rb_2O and Cs_2O, respectively – Černý *et al.*, 1995; Fig. 1.5). All trilithionite types are Li- and F-rich with 2.13 to 3.31 apfu and 2.21 to 2.98 apfu, respectively. Fe-enriched trilithionite IV shows lower concentrations of Li and F – 2.18 and 2.34 apfu, respectively. The concentrations of B are low (0.015 to 0.022 apfu), except trilithionite I with 0.051 apfu (0.065 to 0.083 wt% B_2O_3). Polylithionite exhbits 7.35 apfu Si and 2.59 apfu ${}^{Y}Al$. It is Rb-depleted but Cs-enriched as compared to trilithionite II and III (0.09 apfu Rb and 0.13 apfu Cs; 1.06 wt% Rb_2O and 2.20 wt% Cs_2O). It seems to represent the most fractionated mica in the pegmatite (Fig. 1.5). Polylithionite contains moderate amount of Li (2.66 apfu) but high F (3.44 apfu) relatively to trilithionite II, III and IV. The concentrations of Be are very low, 0.001 to 0.003 apfu in all micas. The following substitution mechanisms were found in micas: $Li_{1.5}\ Al_{-0.5}\ {}^{O}\square_{-1}$ – between muscovite and trilithionite, $Li_2\ Si\ Al_{-2}\ {}^{O}\square_{-1}$ – between trilithionite and polylithionite and $Fe_{0.5}\ {}^{O}\square_{0.5}\ OH\ Li_{-1}F_{-1}$ – between Fe-free trilithionite and Fe-enriched trilithionite.

3.1.4.2 Tourmalines

Three tourmaline parageneses, evidently distinct in their origin (compare Novák & Selway, 1997; Novák *et al.*, 1998c; Selway *et al.*, 1999), were recognized in the Hradisko pegmatite. The first paragenesis involves all of the tourmaline that crystallized in primary pegmatite units (ii) to (vii) and comprises of about 99 vol% of all tourmaline occurring in the pegmatite body. There is no tourmaline in the (i) coarse-grained biotite-bearing wall zone and in the (v) blocky core-margin. The second paragenesis is represented by late, thin fracture-filling veins or fissures, which penetrate most of the primary pegmatite units. The third paragenesis is the metasomatic tourmaline found in rare enclaves of altered metapelites. Both latter parageneses are not presented in detail in this fieldtrip guidebook.

The less evolved textural-paragenetic units (ii) to (iv) contain black **schorl** to **foitite**, which forms isolated columnar crystals, radial aggregates and fine- to medium-grained masses. It is commonly associated with muscovite I; however, tourmaline volumetrically predominates over muscovite in most cases. Tourmaline in the (vi) albite-lepidolite unit is highly variable in colour, zonality, habit and size. Black schorl is typical for outer parts of the albite subunit, but it is mostly rimmed by dark-green or dark-blue Mn-bearing schorl-elbaite. Typically associated minerals include cassiterite I and greenish muscovite II. **Elbaite** is the most common tourmaline of the lepidolite subunit and outer parts of the (vii) quartz core, where it may also occur in small vugs. It forms homogeneous or zoned crystals (Fig. 1.6) and fine- to coarse-grained radial aggregates. Elbaite is commonly pink, locally green, grey, blue and colourless. Very rare pink **rossmanite** occurs in massive trilithionite II.

Disregarding rare grey colour that tourmaline exhibits, the overall colour sequence of tourmaline from Hradisko based on a study of zoned crystals is: black → dark green (dark blue) → green → pink → colourless → green. Terminations of zoned crystals are mostly green, hence the last primary tourmaline to crystallize is greenish Fe-bearing elbaite. Purple to violet trilithionite II and III is commonly associated with pink elbaite or rossmanite. Zoned elbaite with trilitihionite IV occur in small vugs of the quartz core.

Tourmaline from the pegmatite is characterized by a considerable variation in composition from Na-rich foitite, schorl to Al-rich schorl in the less fractionated units, Fe-rich elbaite, Mn-bearing elbaite, elbaite and rossmanite in the albite-lepidolite unit and the quartz core (Fig. 1.6). Most of the tourmaline analyses (electron microprobe) were normalized to 6 Si apfu, so in several wet analyses (Povondra, 1981) black schorl to foitite exhibit rather low variation of Si from 5.92 to 6.06 apfu; elbaite from 5.87 to 6.02 apfu Si. The Z-site is very likely fully occupied by Al in all tourmaline species. Tourmaline in the pegmatite varies considerably in the composition of the Y-site. Low contents of Mg decrease from ≤ 0.30 apfu in the graphic unit via ≤ 0.19 apfu in the granitic unit to ~ 0.00 apfu in tourmaline from the inner units. Only green Fe-bearing elbaite from the quartz core associated with green trilithionite

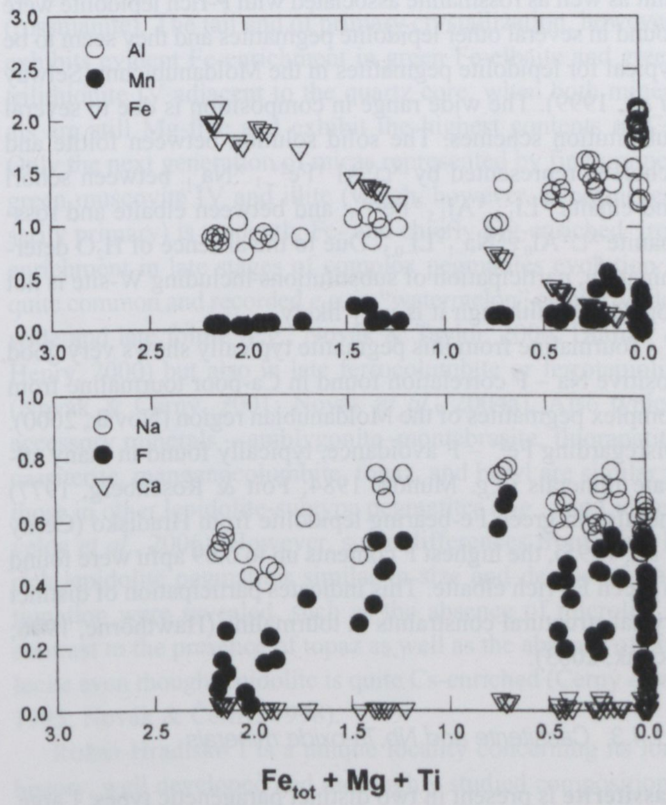


Fig. 1.6. Compositional diagrams of tourmaline from the Rožná-Hradisko pegmatite (Novák, 2000).

IV contains slightly elevated Mg ≤ 0.03 apfu. Behaviour and contents of Mn are variable from ≤ 0.07 apfu in the outer units to ≤ 0.40 apfu in blue Fe-elbaite in the albite subunit (via) to 0.1 apfu in pink elbaite from the lepidolite subunit (vib). Behaviour of Fe is also rather complicated, varying from 2.13 apfu in foitite-schorl from the outer unit to 1.72–0.22 apfu in schorl to elbaite from the albite subunit to very low Fe apfu in pink elbaite. However, green Fe-elbaite associated with trilithionite IV in the lepidolite subunit and in the quartz core reach up to 0.74 apfu and 0.43 apfu Fe^{2+}, respectively. Rossmanite is Fe-free. X-site exhibits low Ca (0.05 apfu in all analyses) and K is about the detection limit; however, Na and X-site vacancy vary in a wide range from X-site vacant foitite (0.60 pfu) and rossmanite (0.58 pfu) to Na-rich, 0.76 apfu Na in green and blue Fe-elbaite. Also W-site shows high variation from F-poor foitite-schorl (0.02-(0.02–0.25 apfu) to 0.54 apfu F in green-blue Fe-elbaite from the albite subunit (via) through to 0.08 apfu F in pink elbaite to late green Fe-elbaite from the quartz core with 0.69 apfu F.

The general compositional trend of tourmaline from lepidolite pegmatite at Hradisko, Rožná is: Na-rich foitite to schorl → Al-rich schorl → Mn-bearing Fe-rich elbaite → rossmanite → elbaite – Fe-bearing elbaite. This increasing fractionation trend of increasing Al and Li, and decreasing Mg and Fe in tourmaline is characteristic for lepidolite pegmatites (Jolliff *et al.*, 1986; Novák & Povondra, 1995; Selway *et al.*, 1999), elevated Fe in late tourmaline is also known (Novák & Taylor, 2000). The X-site deficient Na-foitite from the outermost pegmatite unit as well as rossmanite associated with F-rich lepidolite were found in several other lepidolite pegmatites and they seem to be typical for lepidolite pegmatites in the Moldanubicum (Selway *et al.*, 1999). The wide range in composition is due to several substitution schemes. The solid solution between foitite and schorl is represented by $^{X}\square^{Y}Al\ ^{Y}Fe^{2+}_{-1}\ ^{X}Na_{-1}$; between schorl and elbaite $^{Y}Li_{1.5}\ ^{Y}Al_{1.5}\ ^{Y}Fe^{2+}_{-3}$; and between elbaite and rossmanite $^{X}\square^{Y}Al_{0.5}\ ^{X}Na_{-1}\ ^{Y}Li_{-0.5}$. Due to the absence of H_2O determination, participation of substitutions including W-site is not considered, although it is very likely.

Tourmaline from this pegmatite typically shows very good positive Na – F correlation found in Ca-poor tourmaline from complex pegmatites of the Moldanubian region (Novák, 2000). Disregarding Fe^{2+} – F avoidance, typically found in many silicate minerals (*e.g.* Munoz, 1984; Foit & Rosenberg, 1977) and also in green Fe-bearing lepidolite from Hradisko (Černý *et al.*, 1995), the highest F contents up to 0.69 apfu were found in green Fe-rich elbaite. This indicates participation of distinct crystal structural constraints in tourmaline (Hawthorne, 1996; Novák, 2003).

3.1.4.3. Cassiterite and Nb,Ta-oxide minerals

Cassiterite is present in two distinct paragenetic types. Large, dipyramidal, black-brown crystals of **cassiterite I** and their intergrowths, up to 3 cm in size, are associated with Fe-bearing elbaite and muscovite II in the albite subunit (via), and locally were very abundant. Black isometric grains of **cassiterite II**, commonly ≤ 1 mm in size, occur exclusively in pink trilithionite III and pink elbaite from the lepidolite subunit (vib). Chemical analyses of cassiterite I yielded very low concentrations of TiO_2 (≤ 0.72 wt%), Nb_2O_5 (≤ 0.83 wt%) and Ta_2O_5 (≤ 0.24 wt%) (Vižďa, 2003), which is in contrast with more enriched cassiterite from other localities (see *e.g.*, Novák, 1999; Vižďa, 2003).

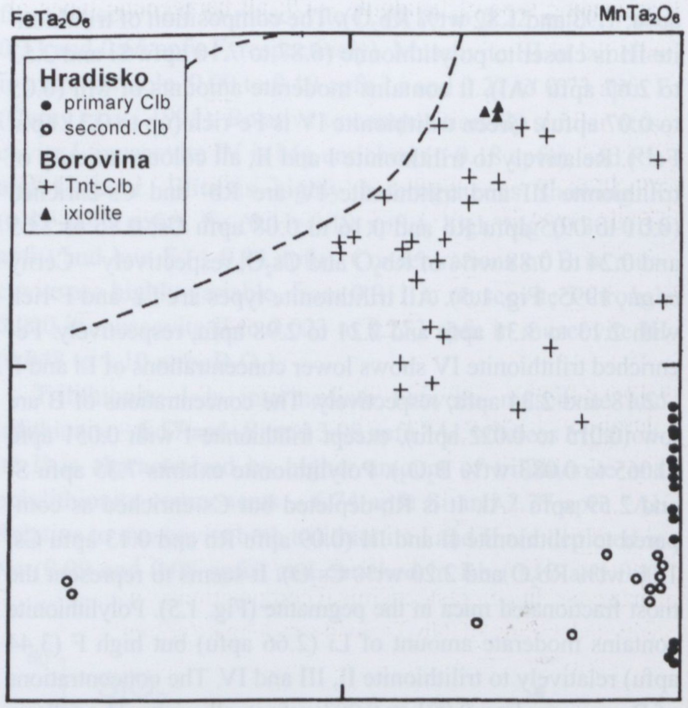


Fig. 1.7. Compositional diagram of Nb-Ta oxide minerals (Novák & Černý, 2001).

Two distinct morphological types of columbite–tantalite occur at Hradisko. Rare microscopic **ferrocolumbite** to **manganocolumbite** inclusions in cassiterite I from the albite subunit (via), which is associated with greenish to colourless muscovite II, black to green (blue) Fe-elbaite, apatite and rare amblygonite-montebrasiteamblygonite–montebrasitemontebrasite II. The second type typically forms black, euhedral to subhedral grains, up to 2 cm in size, with good cleavage and strong submetallic lustre. It occurs exclusively in the lepidolite subunit (vib), mainly close to the quartz core, or within the quartz core closely adjacent to the lepidolite subunit. Columbite seems to be absent in the albite subunit (except for inclusions in cassiterite I), which is a typical columbite-bearing assemblage in most other lepidolite pegmatites in the Moldanubian Zone as discrete grains, up to 1 cm in size, typically associated with discrete grains of cassiterite (*e.g.*, Novák & Diviš, 1996; Novák & Černý, 1998). Disregarding microscopic inclusions in cassiterite I, several distinct paragenetic types of columbite were distinguished: (i) grains of **manganocolumbite I** in fine-grained purple trilithionite III + albite, mostly located close to or penetrating the quartz core (paragenetic type of lepidolite – F9; all paragenetic types of lepidolite from Černý *et al.*, 1995); (ii) **manganocolumbite II** in massive quartz of the quartz core, its grains are locally associated with cassiterite II and purple trilithionite III (type F9); (iii) very rare, anhedral **manganocolumbite III** occur in massive, fine- to medium-grained gray trilithionite III + polylithionite (type H6); (iv) rare, subhedral grains of **manganocolumbite IV** in green trilithionite IV (type H4).

All manganocolumbite samples of the paragenetic types (i), (ii) and (iv) are homogeneous, except for very rare late veins of oscillatorily zoned manganocolumbite to ferrocolumbite found in two samples from the quartz core (Fig. 1.7). Manganocolumbite (iii) from grey trilithionite III is heterogeneous in terms of Nb/Ta with a simple progressive zoning, locally with sharp borders between individual zones (Novák & Černý, 2001). Late oscillatorily zoned ferrocolumbite to manganocolumbite cut in thin veins manganocolumbite II from the quartz core. In contrast, chemical composition as well as compositional trends of Nb-Ta oxide minerals (columbite–tantalite, ixiolite) from the Borovina outcrop are distinct (Fig. 1.7; Novák & Černý, 2001). Columbite from Hradisko also yielded high ordering as compared to samples from Borovina (Fig. 1.7). Also concentrations of minor cations (*e.g.*, Ti, Sn) are much lower at Hradisko.

3.1.4.4 Amblygonite–montebrasite

Amblygonite–montebrasite is present in several distinct paragenetic types as the other minerals. In the blocky core-margin unit, **amblygonite–montebrasite I** is associated with blocky K-feldspar and albite and forms subhedral grains, up to 5 cm in size. Rare **amblygonite–montebrasite II**, as small irregular (to skeletal) grains about 2 cm in size, is present in the albite subunit (via) characterized by greenish to colourless muscovite II, black to green (blue) tourmaline, cassiterite and fluorapatite. Euhedral grains of **amblygonite–montebrasite III**, up to 3 cm in size, are associated with trilithionite III, pink, red, green, blue, grey to colourless elbaite to pink rossmanite, and accessory fluorapatite, topaz, beryl, and cassiterite. **Amblygonite–montebrasite IV** occurs as subhedral grains, up to 15 cm in size, in blocky quartz of the quarz core. Individual types of amblygonite–montebrasite vary from rather fresh (commonly amblygonite–montebrasite IV) through highly altered (various types of amblygonite–montebrasite) to a fine-grained mixture of **lacroixite**, **brazilianite**, **goyazite**, **eosphorite**, **fluorapatite** and **kaolinite** after various types of amblygonite–montebrasite (see also Němec, 1998). Chemical compositions of primary amblygonite–montebrasite as well as its breakdown products were not studied in detail.

3.1.4.5 Additional minerals

Fluorapatite is present in several paragenetic types. The most attractive are perfectly developed grains, perfectly developed violet, green and greyish crystals (Fig. 1.4) that occur in pockets. Irregular grains are common in lepidolite. Secondary apatite present in pseudomorphs after amblygonite-amblygonite–montebrasite was not studied in detail.

Beryl is perhaps more common but colourless to white grains are easily overlooked. Three paragenetic types were recognized (Novák *et al.*, 1998c). In the albite subunit (via) beryl is associated with rare lepidolite and forms elongated grains. Isometric, white grains occur on the contact of the quartz core and pale green trilithionite IV. Large elongated crystals, up to 8 cm long, were found in albite. Beryl is locally Cs-enriched (up to 2.25 wt% Cs_2O 0.09 apfu).

Rare, strongly metamict grains of **zircon,** about 1–2 mm in size, occur in lepidolite. They were not studied in detail, but zircon from the Borovina outrop contains up to 29.67 wt% HfO_2 Zr/Hf = 2.1–2.3 (Novák *et al.*, 1998c).

3.1.5 Concluding remarks

Lepidolite pegmatite from Rožná-Hradisko represents a typical complex (lepidolite subtype) pegmatite with minor micas (biotite-muscovite-lepidolite-illite), and tourmalines (schorl-foitite-elbaite-rossmanite) with characteristic compositional evolution (Černý *et al.*, 1995; Novák & Selway, 1997) similar to other pegmatites of lepidolite subtype (Jolliff *et al.*, 1986, 1987; Novák, 2000; Selway *et al.*, 1999). Micas and tourmalines evolve from the outer units with Fe-high and Mg-moderate contents in biotite and schorl-foitite through muscovite and Fe-elbaite (both Mg-free) to Fe-free trilithionite and elbaite (rossmanite). The tail end of primary crystallization, however, exhibits evident Fe-enrichment in green Fe-elbaite and green trilithionite IV adjacent to the quartz core, when both minerals are still Mg-free and exhibit the highest contents of Cs. Only the next generation of micas represented by fine-grained green muscovite IV and illite (which, however, is not necessarily primary) is evidently Fe- and chiefly Mg-enriched. Iron enrichment in late stages of complex pegmatites evolution is quite common and recorded *e.g.* in "watermelon" elbaite worldwide and late foitite (*e.g.*, Novák & Taylor, 2000; Dutrow & Henry, 2000) but also in late ferrocolumbite or ferrotapiolite (Novák & Černý, 2001; Novák *et al.*, 2004a). Also typical accessory minerals – amblygonite–montebrasite, fluorapatite, cassiterite, manganocolumbite, topaz, and beryl are similar to those in other lepidolite-subtype pegmatites (*e.g.*, van Lichtervelde *et al.*, 2006). However, some differences from other F-rich lepidolite pegmatites similar in size and degree of fractionation were revealed, such as the absence of microlite in contrast to the presence of topaz as well as the absence of pollucite even though lepidolite is quite Cs-enriched (Černý *et al.*, 1995; Novák & Černý, 1998).

Rožná-Hradisko I is a unique locality concerning its long history, well developed and thoroughly studied compositional evolution of micas and tourmalines. Also lepidolite and rossmanite were described here as new species for the first time.

Internal structure, mineralogy, chemistry of minerals and compositional trends indicate that the Rožná lepidolite pegmatite is the largest complex pegmatite in the Moldanubian Zone. Its mineral assemblage and composition of minerals are very similar to that of the lepidolite pegmatites in Varuträsk in Sweden; Brown Derby in Colorado, USA; Bob Ingersoll, Black Hills, South Dakota, USA and many others.

3.2 Field stop 2: Oslavice near Velké Meziříčí – NYF pegmatites of allanite and euxenite type of the Třebíč Pluton

(Radek Škoda & Milan Novák)

3.2.1 Introduction to the geological situation of the Třebíč Pluton and its NYF pegmatites

Intragranitic pegmatites of NYF family occur exclusively in the Variscan syenite plutons in the Moldanubian Zone – the Třebíč Pluton, western Moravia, and the Čertovo břemeno (Milevsko) Pluton, southern Bohemia (see Fig. 1.1). Both plutons form large syn-exhumation tabular bodies (Žák *et al.*, 2005) interpreted as a product of mixing between enriched mantle magma and a crustal melt (Holub *et al.*, 1997b; Janoušek *et al.*, 2000). These orogenic syenogranites belong to shoshonitic association of the ultrapotassic plutonic rocks (MgO > 3 wt%, $K_2O/Na_2O > 2$; Foley *et al.*, 1987) and similar rocks of the durbachite series are known from the Black Forest, Germany and from the Vosges, France (Holub *et al.*, 1997b).

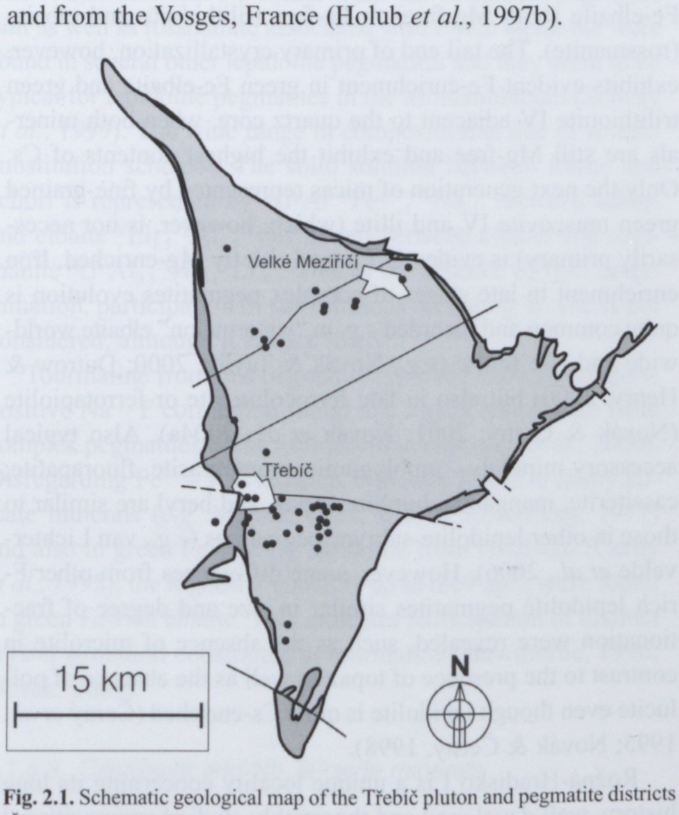


Fig. 2.1. Schematic geological map of the Třebíč pluton and pegmatite districts (Škoda *et al.*, 2006).

Light grey – melagranite to melasyenite; dark grey – leucocratic granites; dots – pegmatite occurrences.

The Třebíč Pluton, parental granite-syenite of NYF pegmatites, forms a large (~540 km²), tabular body, emplaced in medium- to high-grade metamorphic rocks (cordierite migmatites, biotite-sillimanite gneisses; Fig. 2.1). Porphyric, amphibole-biotite melasyenite to quartz melasyenite and melagranite is locally foliated to various degrees mainly near contacts with host rocks. The granite-syenite is composed of subhedral orthoclase crystals, up to 3 cm in size. These are enclosed in a medium- to fine-grained matrix consisting of abundant Fe-phlogopite ($X_{Fe} = 0.32–0.35$), oscillatory-zoned plagioclase ($An_{8–40}$), quartz and amphibole (actinolite to rare magnesiohornblede, $X_{Fe} \approx 0.2$). Amphibole locally contains relics of diopside and very rare orthopyroxene. Accessory minerals include abundant fluorapatite, zircon and titanite along with rare allanite-(Ce), thorite, thorianite, monazite-(Ce), xenotime-(Y), cheralite and sulphides (pyrrhotite >> pyrite) (Sulovský, 2000). They were classified by Finger *et al.* (1997) as high-K, *I*-type granitoids characterized by metaaluminous signature and high content of K_2O (5.2–6.5 wt%), MgO (3.3–10.4 wt%), P_2O_5 (0.47–0.98 wt%), Rb (330–410 ppm), Ba (1100–2470 ppm), U (6.7–26.2 ppm), Th (28.2–47.7 ppm), Cr (270–650 ppm), Cs (20–40 ppm), and high K/Rb ratio = 133–171. Radiometric dating (Pb-Pb zircon) indicates a Lower Carboniferous age of 343±6 Ma (Holub *et al.*, 1997a).

In the Třebíč Pluton, NYF granitic pegmatites vary from primitive allanite-type pegmatites through more evolved euxenite-type pegmatites to specific zinnwaldite-masutomilite-elbaite pegmatite from Kracovice near Třebíč cutting gneiss near the border of the pluton (Škoda *et al.*. 2006; Škoda & Novák, 2007).

Allanite-type pegmatites form segregations with coarse-grained granitic texture to simply zoned dikes about 1–5 dm in size. The internal structure of zoned dikes is composed of an outer medium- to coarse-grained granitic zone (K-feldspar + quartz + oligoclase + phlogopite ± amphibole) and an inner blocky K-felspar unit. The graphic (microcline + quartz) unit is also present at some dikes. Tourmaline, ilmenite, titanite, and allanite-(Ce) are typical accessory minerals.

Euxenite-type pegmatites as dikes and lenses, up to 2 m thick, with sharp to transitional contacts to host granite-syenite, show zoned internal structure from the contact inwards: a border medium- to coarse-grained granitic unit (K-feldspar + quartz + oligoclase + phlogopite ± amphibole), a graphic unit (microcline + quartz, scarcely albite + quartz), a core built up by blocky K-feldspar, and a locally developed quartz core. A fine-grained aplitic unit is asymmetrically located between the granitic and graphic unit at some localities. A medium- to coarse-grained albite unit is developed between the blocky K-feldspar and quartz or in blocky K-feldspar and graphic unit. Very rare, small pockets, lined with crystals of K-feldspar, quartz, albite, titanite and very rare phenakite or beryl occur in some euxenite pegmatites. Mineral composition of the pegmatites is characterized by dominance of K-feldspar (locally pale green amazonite) over albite, common Mg-rich biotite

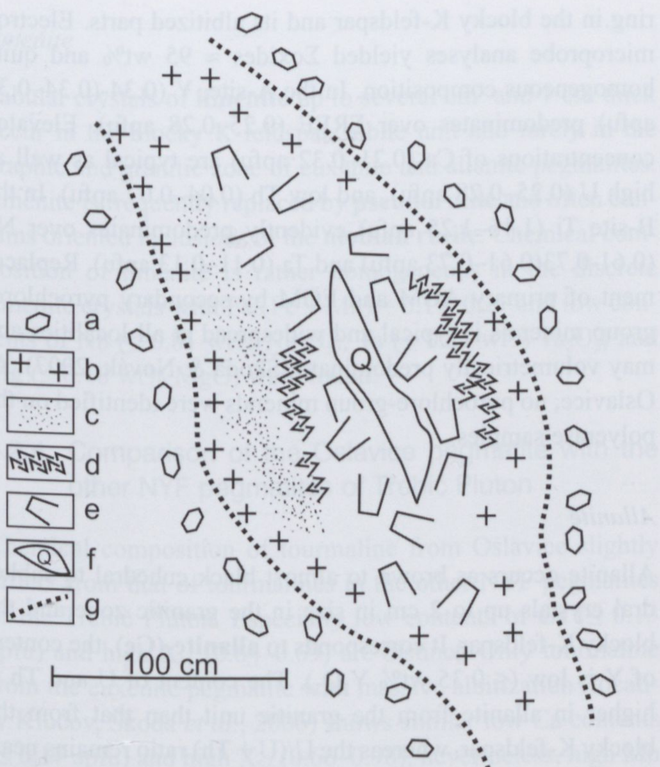


Fig. 2.2. Vertical section through the pegmatite from the Třebíč Pluton.
a): host granite–syenite (durbachite); b): granitic unit; c): aplitic unit; d): graphic unit; e): blocky K-feldspar; f): massive quartz; g): contact, locally transitional (modified from Škoda et al., 2006).

(X_{Fe} = 0.30–0.51) and absence of primary muscovite. Typical accessory minerals include common allanite-(Ce), aeschynite and euxenite group minerals), titanite I, ilmenite, niobian rutile, actinolite, zircon, monazite-(Ce), beryl, and phenakite. Tourmaline is a typical minor to accessory mineral in some euxenite pegmatites but rather rare in allanite pegmatites. Abundant alteration products include bavenite, bazzite, milarite, beryl II, bertrandite, chlorite, pyrochlore group minerals, pseudorutile and titanite II.

The specific ***zinnwaldite-masutomilite-elbaite*** pegmatite is located only several hundreds of meters W of the western border of the Třebíč pluton near Kracovice. The pegmatite dike (~1 m thick) cuts the graphitic gneiss and crops out in the agricultural field. The internal structure comprises from the contact invards: a granitic unit, a graphic unit, a blocky K-feldspar unit, a blocky quartz and an albite complex situated close to a quartz core. Major minerals are represented by quartz (commonly smoky), K-feldspar (locally amazonite), and albite (saccharoidal and cleavelandite). Typical subordinate minerals are micas (muscovite, zinnwaldite, lepidolite to masutomilite) and tourmalines (schorl, elbaite), the accessory minerals include topaz, spessartine ($Sps_{71-61}Alm_{29-39}$; 1.5 wt% Y_2O_3), F-rich hambergite, monazite-(Ce), xenotime-(Y), zircon (Zr/Hf ≈ 20), columbite, wolframoixiolite, cassiterite, fergusonite-(Y), samarskite and pyrochlore group minerals. Secondary and fracture-filling minerals comprise beryl, bertrandite, bavenite and fluorite (Novák *et al.*, 1999b). Chemical composition and compositional trends of tourmalines, micas and hambergite are different from those observed in LCT pegmatites (elbaite or lepidolite subtype). The compositional trend in micas is similar to those found in some F-rich NYF pegmatites (*e.g.* Pikes Peak, Colorado). The Kracovice pegmatite probably belongs to the mixed NYF/LCT family and it is similar to the pegmatites at Tørdal, Norway (Bergstøl & Juve, 1988; Raade *et al.*, 1993, 2004).

3.2.2 Geology and internal structure

The NYF pegmatites are common in two individual regions within the Třebíč Pluton, the southern segment (Třebíč-Vladislav), where a majority of more evolved pegmatites occurs, and the northern segment (Velké Meziříčí-Bochovice; Škoda *et al.*, 2006; Fig. 2.1). Most pegmatite bodies crops out in agricultural fields, only a few pegmatites are well exposed at natural outcrops or as large boulders (up to 3 m³). At the locality Oslavice (the northern segment), located close to the NW border of the Třebíč pluton, allanite- and euxenite-type pegmatite yields one of the best outcrop in a roadcut situated W of the village. They form irregular, homogeneous to simply zoned dikes, up to 50 cm thick and several m long (Fig. 2.2). Thin dikes merge to thick ones and split again. Pegmatite bodies are mostly horizontal in Oslavice, whereas vertical to subvertical dikes are typical in the southern segment (Třebíč-Vladislav).

The pegmatites show sharp to locally transitional contacts (usually within one dike) between an outer zone and the host coarse-grained granite-syenite. Both euxenite-type and less evolved pegmatites of allanite type are present. Thin dikes (~1–2 dm thick) consist only of a medium- to coarse-grained granitic unit; if the dike becomes swollen, blocky K-feldspar and small pockets occur. Some thick dikes (~0.5 m) show asymmetrical internal zoning; the outer granitic unit is developed only at the footwall side, whereas at the hanging wall the blocky K-feldspar propagates directly from the contact. Albite occurs around massive quartz or pockets.

3.2.3 Mineralogy

Overall mineralogy of both allanite and euxenite-type pegmatites from Oslavice is very similar to that of the relevant pegmatites of the Třebíč Pluton, which were studied in detail by Škoda *et al.* (2006) and Škoda & Novák (2007). Major minerals (quartz – commonly smoky, K-feldspar, albite, and biotite) were not studied in detail, in contrary to the accessory phases (*e.g.* Fig. 2.3).

Tourmaline

Presence of tourmaline is characteristic for the majority of euxenite-type pegmatites, but it is rather scarce in allanite-type pegmatites. Tourmaline generally occurs as i) prismatic tourmaline (from blocky K-feldspar), ii) nodular tourmaline

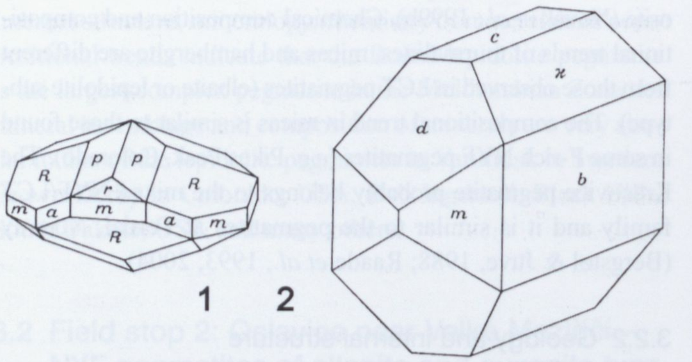


Fig. 2.3. Crystals from Třebíč Pluton pegmatites.
1 – phenakite from Třebíč (Staněk, 1973b); 2 – priorite from Pozďátka (Čech, 1957).

(tourmaline nodules, up to 5 cm in size, with leucocratic rim from the aplitic zone in some euxenite pegmatites), iii) graphic intergrowths of quartz and tourmaline from more evolved euxenite pegmatites and iv) interstitial tourmaline fills microfractures mostly in the blocky K-feldspar (Škoda *et al.*, 2006). Solely prismatic and interstitial textural types of tourmaline were observed at Oslavice. Their typical features are high content of Ti (0.39 apfu), moderate Ca (≤ 0.16 apfu), low X-site vacancy (≤ 0.16 pfu), low amount of Al (5.30–5.86 apfu), and F (≤ 0.02 apfu), and X_{Fe} = 0.64–0.69. This tourmaline corresponds to Al-deficient **schorl** (Fig. 2.4).

Y-REE-Nb-Ta-Ti oxide minerals

Primary aeschynite group minerals (AGM) and euxenite group minerals (EGM) occur as light to dark brown, rarely yellow-brown, red-brown to almost black grains with resinuous, semimetallic or vitreous luster, and conchoidal fracture, exclusively in euxenite-type pegmatites (Fig. 2.5). Only **polycrase-(Y)** was identified at Oslavice as needle-like, subhedral to anhedral grains, commonly 3–10 mm long, typically occurring in the blocky K-feldspar and its albitized parts. Electron microprobe analyses yielded Σoxides ≈ 95 wt% and quite homogeneous composition. In the A-site, Y (0.34-(0.34–0.38 apfu) predominates over ΣREE (0.25–0.28 apfu). Elevated concentrations of Ca (0.21–0.32 apfu) are typical as well as high U (0.25–0.28 apfu), and low Th (0.04–0.07 apfu). In the B-site Ti (1.16–1.25 apfu) evidently predominates over Nb (0.61-0.73(0.61–0.73 apfu) and Ta (0.11–0.13 apfu). Replacement of primary AGM and EGM by secondary pyrochlore-group minerals is typical and widespread at all localities and may volumetrically predominate (Škoda & Novák, 2007). At Oslavice, no pyrochlore-group minerals were identified on the polycrase samples.

Allanite

Allanite occurs as brown to almost black euhedral to subhedral crystals up to 2 cm in size in the granitic zone and the blocky K-feldspar. It corresponds to **allanite-(Ce)**, the content of Y is low (≤ 0.35 wt% Y_2O_3). The content of U and Th is higher in allanite from the granitic unit than that from the blocky K-feldspar, whereas the U/(U + Th) ratio remains nearly the same. Elevated content of radioactive elements causes transformation from crystalline to amorphous matter. Secondary REE minerals (**rhabdophane-(Ce), bastnaesite-(Ce)**) replace highly hydrated metamict allanite-(Ce).

Titanite

Euhedral, grey to brown crystals of titanite, up to 3 cm in size, occurs in the coarse-grained granitic unit, blocky K-feldspar, and rarely in small pockets. Titanite is slightly enriched in Nb, Ta, Y and REE (≤ 1.45 wt% Nb_2O_5, ≤ 0.65 wt% Ta_2O_5, 2.93 wt% Y, REE_2O_3). The content of Al_2O_3, SnO_2, and F do not exceed 1.65, 0.29 and 0.12 wt%, respectively.

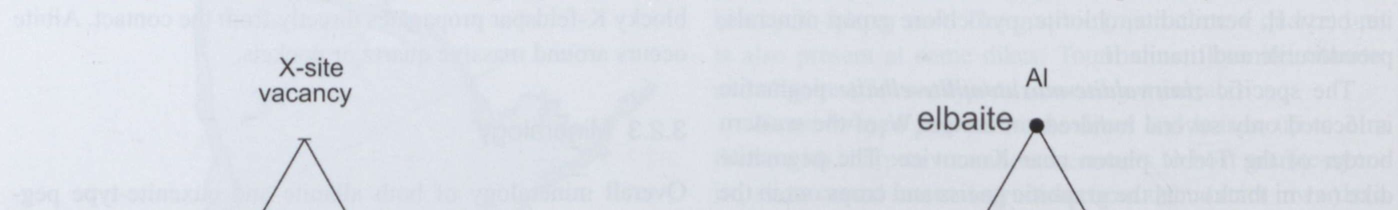


Fig. 2.4. Compositional diagrams of tourmaline.
Light grey – tourmaline from allanite and euxenite pegmatites, dark grey – tourmaline from euxenite pegmatite Klučov I (modified from Škoda et al., 2006).

Ilmenite

Tabular crystals of **ilmenite** up to several cm^2 and 1 cm thick occur in the blocky K-feldspar, albite unit and rarely in the graphic and granitic zone of euxenite and allanite pegmatites. Ilmenite is frequently replaced by **pseudorutile** and often contains oriented inclusions of the **niobian rutile**. Chemical composition of ilmenite is rather homogeneous in the discrete ilmenite crystals with Fe/(Fe + Mn) = 0.19–0.21 and low contents of Nb (≤ 0.81 wt% Nb_2O_5), Ta (≤ 0.31 wt% Ta_2O_5) and Mg (≤ 0.18 wt% MgO) were found.

3.2.4. Comparison of the Oslavice pegmatite with the other NYF pegmatites of Třebíč Pluton

Chemical composition of tourmaline from Oslavice slightly differs from that of tourmalines in the other NYF pegmatites of the Třebíč Pluton. Especially low contents of Ca (≤ 0.13 apfu) and high X_{Fe} (0.64–0.69) are distinct. Only tourmaline from the euxenite pegmatite with massive albitization (locality Klučov, Škoda *et al.*, 2006) shows similar low Ca contents (≤ 0.17 apfu) and high X_{Fe} (0.66–0.98), nevertheless, high Mn (≤ 0.43 apfu) and F (≤ 0.51 apfu) are typical at this locality as compared to Oslavice, where both Mn and F yielded ≤ 0.03 apfu. The low Al and high Ti contents are similar to tourmaline from other allanite and euxenite pegmatites of the Třebíč Pluton (5.07–5.88 apfu Al and ≤ 0.36 apfu Ti) with the exception of the pegmatite with massive albitization (Klučov), where Al attains up to 6.66 apfu in a graphic tourmaline.

Chemical composition of **polycrase-(Y)** (the only euxenite-group mineral found in pegmatites of the Třebíč Pluton; Škoda & Novák, 2007) from the other pegmatites are slightly different from that of polycrase-(Y) at Oslavice. In the A-site, the contents of Y and REE are similar but more variable (0.36–0.48 and 0.27–0.34 apfu, respectively). The concentrations of Ca and U are significantly lower (0.04–0.14 and 0.08–0.16 apfu, respectively), but similar Th content (0.04–0.07 apfu) was found. U/(U + Th) = 0.63–0.70 is lower than that in Oslavice. Occupancy of the B-site is more variable: Ti (1.06–1.34 apfu), Nb (0.34–0.81 apfu) and Ta (0.10–0.32 apfu).

Besides polycrase-(Y), minerals of the aeschynite group were found in most euxenite pegmatites of the Třebíč Pluton. Their chemical composition is more variable and the following mineral species were identified: **aeschynite-(Y)**, **aeschynite-(Ce)**, **aeschynite-(Nd)**, **nioboaeschynite-(Ce)**, ***tantalaeschynite-(Ce)***, and **vigezzite** (Škoda & Novák, 2007). The A-site occupancy is highly variable: ΣREE (0.26–0.50 apfu), Ca (0.22–0.51 apfu), and Y (0.05–0.22 apfu). The concentrations of U and Th are lower as compared to REE, Ca and Y: U (0.00–0.09 apfu), Th (0.02–0.09 apfu) and U/(U + Th) = 0.00–0.55. In the B-site Ti (0.59–1.18 apfu) usually prevails over Nb (0.61–0.98 apfu) and Ta is often high (0.11–0.78 apfu).

Chemical composition of primary **titanite I** from Oslavice is similar to that of titanite from other localities. At several pegmatites, secondary **titanite II** occurs as a product of ilmenite alteration. It is enriched in Sn (0.02–0.14 apfu), contents of Nb and Ta are similar (≤ 0.06 apfu Nb and ≤ 0.01 apfu Ta). The Al content varies from 0.03 to 0.07 apfu, the F content is low (≤ 0.04 apfu).

The overall mineral assemblages from Oslavice pegmatite suggest the presence of relatively less evolved euxenite-type pegmatites and allanite-type pegmatites. Extensive albite unit, abundant graphic intergrowths of quartz and tourmaline, more abundant Y-REE-Nb-Ta-Ti oxides and presence of beryl, typical

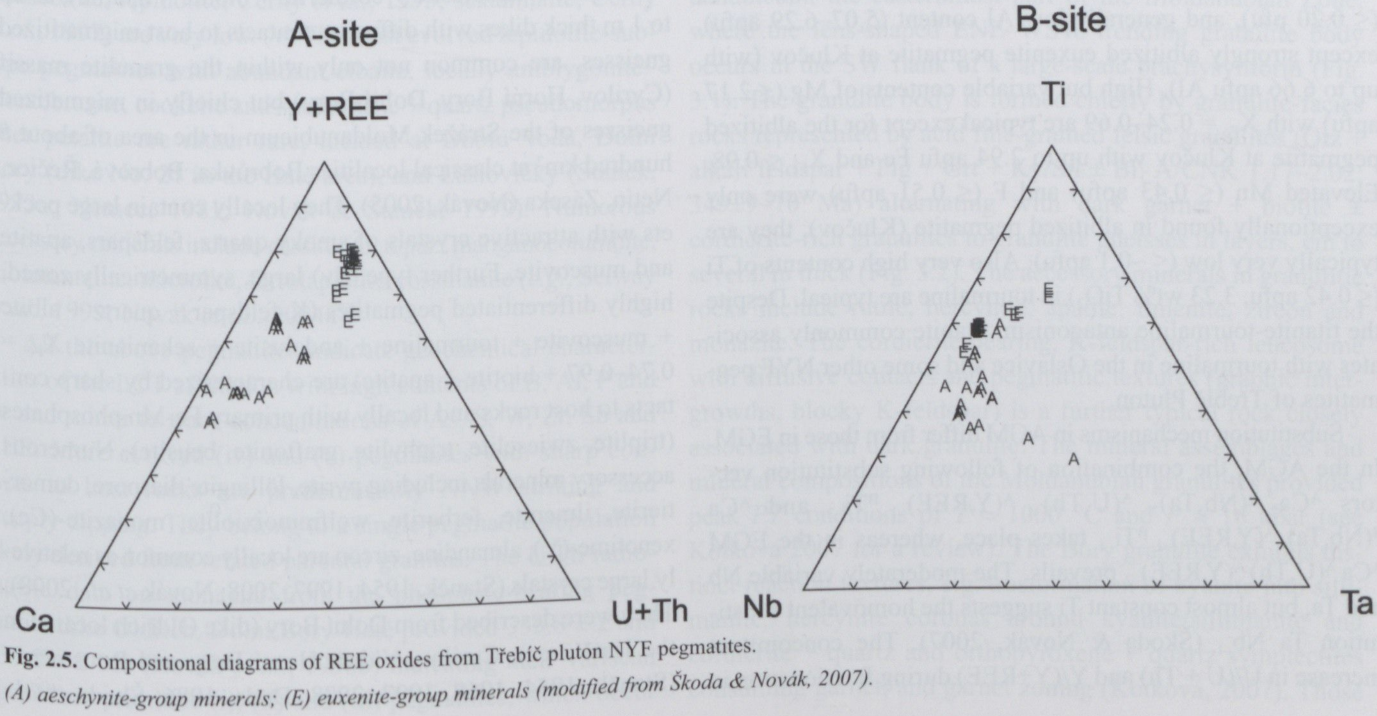


Fig. 2.5. Compositional diagrams of REE oxides from Třebíč pluton NYF pegmatites.
(A) aeschynite-group minerals; (E) euxenite-group minerals (modified from Škoda & Novák, 2007).

for more evolved euxenite-type pegmatites, were not observed. Subhorizontal orientation of pegmatite dikes in the northern segment of the Třebíč Pluton is also distinct, because more less vertical dikes crop out in the southern segmant (Třebíč-Vladislav).

3.2.5. Concluding remarks

The pegmatites from Oslavice are represented by allanite and euxenite type. Their internal structure, mineral assemblage as well as the degree of fractionation derived from the chemical composition of tourmaline and polycrase-(Y) suggest the euxenite pegmatite to be less evolved as compared to many euxenite pegmatites at the southern segment (*e.g.*, Kožichovice, Klučov) characterized by the presence of beryl and aeschynite-group minerals.

Granite-syenite and associated pegmatites of the Třebíč Pluton may be classified as NYF pegmatites related to an orogenic suite (Martin & De Vito, 2005), or NYF-I (niobium-yttrium-fluorine – *I*-type granite related) pegmatites related to syn- to late-orogenic granites (Černý & Ercit, 2005). However, their mineralogy and the chemical composition of some minerals, chiefly of the primary Fe,Mg-bearing minerals with very low X_{Fe} (amphibole 0.21–0.23, biotite 0.30–0.51, beryl 0.14–0.29, tourmaline 0.24–0.98) are compositionally distinct from those in typical anorogenic NYF pegmatites (*e.g.*, Baveno, Italy; Trout Creek Pass, Colorado), where Fe>>Mg is typical in relevant minerals (Aurisicchio *et al.*, 2001; Hanson *et al.*, 1992). Such a very low degree of fractionation in granitic pegmatites of the Třebíč Pluton in the term of Mg/Fe, comparable with their parental granite and distinct from most NYF pegmatites worldwide, supports a unique position of granitic pegmatites of the Třebíč Pluton (see Martin & De Vito, 2005).

The individual minerals also exhibit further specific features in chemical composition. Tourmaline is characterized by high contents of Ca (≤ 0.40 apfu), low vacancy in the X site (≤ 0.20 pfu), and generally low Al content (5.07–6.29 apfu) except strongly albitized euxenite pegmatite at Klučov (with up to 6.66 apfu Al). High but variable contents of Mg (≤ 2.17 apfu) with X_{Fe} = 0.24–0.69 are typical except for the albitized pegmatite at Klučov with up to 2.94 apfu Fe and X_{Fe} ≤ 0.98. Elevated Mn (≤ 0.43 apfu) and F (≤ 0.51 apfu) were only exceptionally found in albitized pegmatite (Klučov), they are typically very low (< ~0.1 apfu). Also very high contents of Ti (≤ 0.42 apfu, 3.23 wt% TiO_2) in tourmaline are typical. Despite the titanite-tourmaline antagonism, titanite commonly associates with tourmaline in the Oslavice and some other NYF pegmatites of Třebíč Pluton.

Substitution mechanisms in AGM differ from those in EGM. In the AGM, the combination of following substitution vectors $^{A}Ca_2\,^{B}(Nb,Ta)_3\,^{A}(U,Th)_{-1}\,^{A}(Y,REE)_{-1}\,^{B}Ti_{-3}$ and $^{A}Ca\,^{B}(Nb,Ta)\,^{A}(Y,REE)_{-1}\,^{B}Ti_{-1}$ takes place, whereas in the EGM $^{A}Ca\,^{A}(U,Th)\,^{A}(Y,REE)_{-2}$ prevails. The moderately variable Nb and Ta, but almost constant Ti suggests the homovalent substitution Ta Nb_{-1} (Škoda & Novák, 2007). The concomitant increase in U/(U + Th) and Y/(Y+REE) during fractionation in AGM and EGM is similar to the trends described by Ercit (2005b). However, Nb/Ta fractionation is generally weak and opposite of the fractionation trends expressed by U/(U + Th) and Y/(Y + REE). This trend is distinct from that described by Ercit (2005b) in complex Y-REE-Nb-Ta-Ti oxide minerals from REE-enriched pegmatites in Ontario.

3.3 Field stop 3: Horní Bory near Velké Meziříčí – Various abyssal pegmatites in rocks of the Bory Granulite Massif

(Jan Cempírek & Milan Novák)

3.3.1 Introduction to granitic pegmatites of the Bory granulite massif

Bory pegmatite district is located within the area of granulitic rocks of the Bory granulite massif, Gföhl Unit, in the easternmost part of the Moldanubian Zone (Fig. 3.1). Granulites are surrounded by high-grade cordierite migmatites and biotite-sillimanite migmatitic gneisses. The pegmatite comprises several distinct types of granitic pegmatites with different origin, size, internal structure as well as degree of geochemical fractionation. (i) Very rare borosilicate-bearing mineral assemblage (grandidierite–ominelite, boralsilite, werdingite, tourmaline, dumortierite) occurs in a thin veinlet (K-feldspar + Qtz) crosscutting the foliation of the host leucogranulite (Cempírek *et al.*, 2009). (ii) Common, subhomogeneous, pegmatitic, cordierite-rich leucosome (K-feldspar + quartz + plagioclase + cordierite X_{Fe} = 0.50–0.44 + biotite) as irregular masses to dikes, up to several dm thick, represents the second type (Povondra *et al.*, 1992; Kotková *et al.*, 2003a). (iii) Simply zoned, primitive pegmatites (K-feldspar + quartz + plagioclase + muscovite + tourmaline + andalusite + cordierite + biotite + apatite), as up to 1 m thick dikes with diffusive contacts to host migmatitized gneisses, are common not only within the granulite massif (Cyrilov, Horní Bory, Dolní Bory) but chiefly in migmatized gneisses of the Strážek Moldanubicum in the area of about a hundred km^2 at classical localities Bobrůvka, Bobrová, Řečice, Netín, Záseka (Novák, 2005). They locally contain large pockets with attractive crystals of smoky quartz, feldspars, apatite and muscovite. Further type, (iv) large, symmetrically zoned, highly differentiated pegmatites (K-feldspar + quartz + albite + muscovite + tourmaline + andalusite + sekanianite X_{Fe} = 0.74–0.97 + biotite + apatite) are characterized by sharp contacts to host rocks and locally with primary Fe-Mn phosphates (triplite, zwieselite, triphylite, graftonite, beusite). Numerous accessory minerals including pyrite, löllingite diaspore, dumortierite, ilmenite, ferberite, wolframoixiolite, monazite-(Ce), xenotime-(Y), almandine, zircon are locally common as relatively large crystals (Staněk, 1954, 1997, 2008; Novák *et al.*, 2008); They were described from Dolní Bory (dike Oldřich located in the Hatě area), Cyrilov, Vídeň, Horní Bory and Rousměrov (Staněk, 1954, 1968, 1997, 2008; Duda, 1986; Škoda *et al.*,

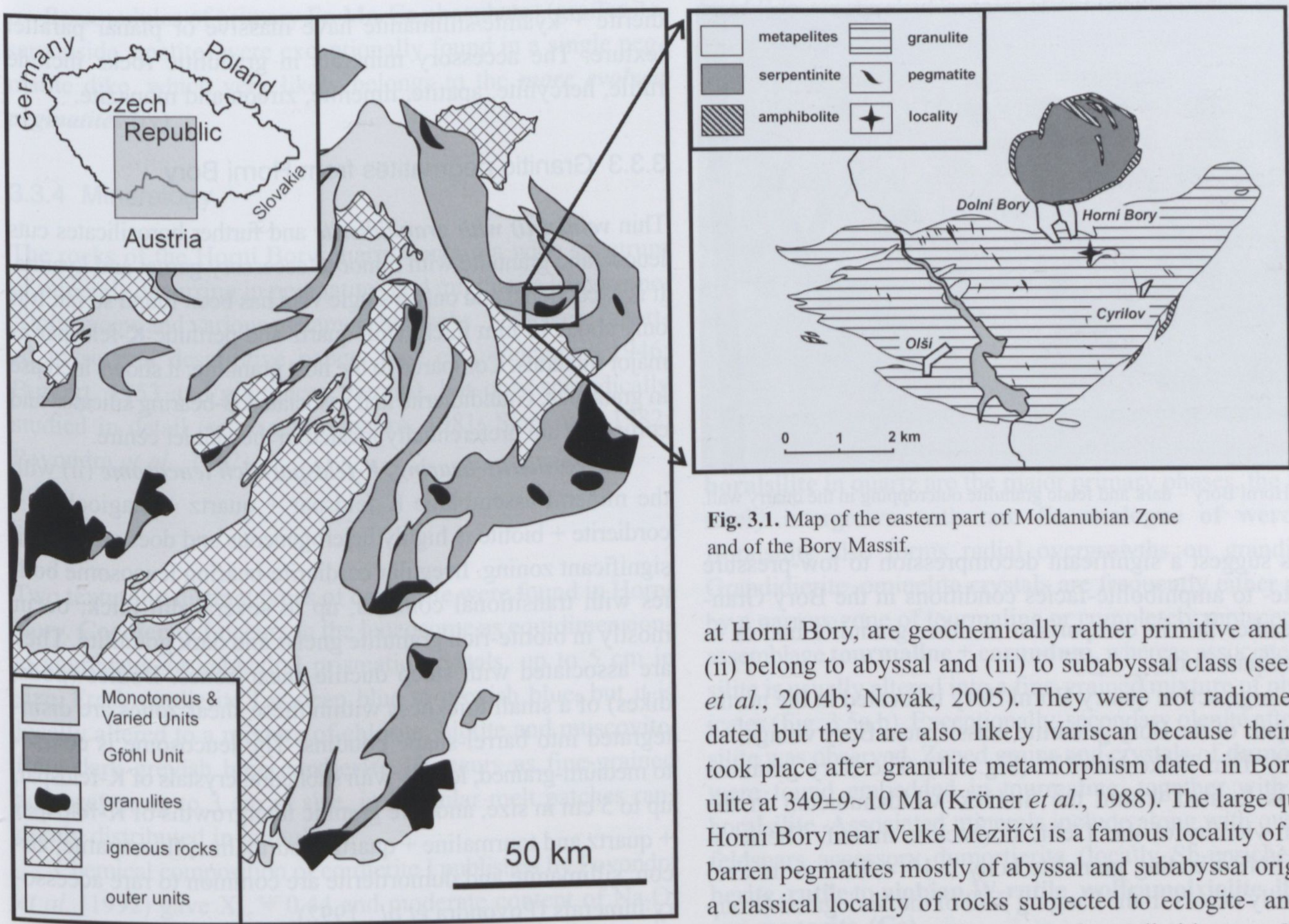


Fig. 3.1. Map of the eastern part of Moldanubian Zone and of the Bory Massif.

2007). Their mineral assemblages and internal structure indicate close relations to the beryl-columbite-phosphate subtype (Černý & Ercit, 2005); however, beryl is absent in the whole pegmatite district and also Be-contents in relevant minerals (muscovite, lepidolite, Černý *et al.*, 1995; sekaninaite, Černý *et al.*, 1997) are very low. (v) The most evolved lepidolite-subtype pegmatites with abundant elbaite, locally amblygonite–montebrasite, cookeite and spodumene + quartz pseudomorphs after petalite are rather rare, located at Dobrá Voda, Dolní Bory (dike No. 21 in the Hatě area), and Laštovičky (Staněk, 1973a; Němec, 1981; Novák & Staněk, 1999). Numerous accessory minerals include cassiterite, topaz, manganocolumbite, stibiotantalite, microlite, ferrotapiolite, rossmanite (*e.g.*, Selway *et al.*, 1999; Novák *et al.*, 2004a).

All the above pegmatites indicate geochemical characteristics of the LCT affiliation with high contents of B, Al, P and Fe and minor to trace concentrations of As, S, W, Zr, Sb and REE. More evolved (iv) and (v) pegmatites with sharp contacts to host rocks are predominantly NNW striking and steeply dipping. They belong to a single pegmatite population likely derived from related parental granites. The U-Pb radiometric data on monazite from the phosphate-bearing pegmatite dike Oldřich, Dolní Bory-Hatě provided 335.8 ± 2 and 337.2 ± 2 Ma (Novák *et al.*, 1998b) indicating their Variscan age. More primitive (i), (ii) and (iii) pegmatites, which occur at Horní Bory, are geochemically rather primitive and (i) and (ii) belong to abyssal and (iii) to subabyssal class (see Novák *et al.*, 2004b; Novák, 2005). They were not radiometrically dated but they are also likely Variscan because their origin took place after granulite metamorphism dated in Bory granulite at 349±9~10 Ma (Kröner *et al.*, 1988). The large quarry at Horní Bory near Velké Meziříčí is a famous locality of various barren pegmatites mostly of abyssal and subabyssal origin, and a classical locality of rocks subjected to eclogite- and granulite-facies metamorphism (recently studied by *e.g.*, Medaris *et al.*, 1995; Ackerman *et al.*, 2009).

3.3.2 Geology

The Bory Granulite Massif is located in the Strážek Moldanubicum, the easternmost part of the Moldanubian Zone, where the lens-shaped ENE–WSW trending granulite body occurs in the SW flank of a large-scale brachysynform (Fig. 3.1). The granulite body is formed chiefly by granulite-facies rocks represented by acid fine-grained felsic granulites (Qtz + alkali feldspar + Plg + Grt + Ky/Sil ± Bi; A/CNK 1.17–2.02; 349±9~10 Ma) alternating with dark garnet + biotite ± cordierite-rich granulites to granulite gneisses in layers, cm to several m thick (Fig. 3.2). The accessory minerals in granulitic rocks include rutile, hercynite, apatite, ilmenite, zircon and monazite. The cordierite-bearing, K-feldspar-rich leucosome with diffusive contacts and pegmatitic textures (graphic intergrowths, blocky K-feldspar) is a further typical rock closely associated with dark granulite. The mineral assemblages and mineral compositions of the Moldanubian granulites provided peak *PT* conditions of $T \approx 1000$ °C and $P \approx 16$ kbar (see Kotková 2007 for a review). The Bory granulite exhibits distinct reaction textures, e.g. trasformation of kyanite into sillimanite, hercynite coronas around kyanite/sillimanite and cordierite + quartz and orthopyroxene + quartz symplectites consuming garnet, and garnet zoning (Kotková, 2007). Those

Fig. 3.2. Horní Bory – dark and felsic granulite outcropping in the quarry wall.

textures suggest a significant decompression to low-pressure granulite- to amphibolite-facies conditions in the Bory Granulite, reather fast in comparison to other granulite bodies in Moldanubian Zone.

The large active quarry Horní Bory is located in the north-eastern part of the Bory granulite massif, near Bory village, ~6 km north from Velké Meziříčí (Fig. 3.1). The Bory granulite massif is located within the Strážek Moldanubicum in the northern vicinity of the Třebíč durbachite massif. The lens-shaped ENE-trending granulite body (~10 × 3.5 km in size) structurally occurs in the hanging wall of the Variegated Group and is formed predominantly by granulite-facies crustal rocks. Within the granulites, boudins of mafic and ultramafic rocks, up to several m in size, occur. The foliation in granulites generally slightly dipping to the northwest is folded by large- and small-scale upright to moderately inclined folds.

The granulite-facies rocks are represented by fine-grained felsic granulites with the mineral assemblage quartz + alkali feldspar + plagioclase + garnet + kyanite/sillimanite ± biotite, alternating with dark garnet + biotite ± cordierite-rich granulites (so-called "hornfels granulites") to granulite gneisses in layers, cm to m thick. The granulite gneisses with the mineral assemblage quartz + K-feldspar + plagioclase + garnet + cordierite + kyanite/sillimanite have massive or planar parallel texture. The accessory minerals in granulitic rocks include rutile, hercynite, apatite, ilmenite, zircon and monazite.

3.3.3 Granitic pegmatites from Horní Bory

Thin ***veinlet (i) with grandidierite*** and further borosilicates cuts leucocratic granulite with minor to accessory garnet and kyanite. It is exceptional and only a single vein has been found so far. It is only about 10 mm thick, with quartz and perthitic K-feldspar as major minerals. Compared to the host granulite, it shows increase in grain size. Grandidierite and associated B-bearing silicates and corundum are preferentially located in the veinlet centre.

The ***cordierite-bearing, K-feldspar-rich leucosome*** (ii) with the mineral assemblage K-feldspar + quartz + plagioclase + cordierite + biotite is highly heterogeneous and does not exhibit significant zoning. Irregular cordierite-bearing leucosome bodies with transitional contacts, up to several dm thick, occur mostly in biotite-rich granulite gneiss and dark granulite. They are associated with steep ductile shear zones. Bodies (pods, dikes) of a small thickness within these shear zones are disintegrated into barrel-shape boudins. The leucosome is coarse- to medium-grained, locally with subhedral crystals of K-feldspar, up to 5 cm in size, and rare graphic intergrowths of K-feldspar + quartz and tourmaline + quartz. Tourmaline, fluorapatite, zircon, sillimanite and dumortierite are common to rare accessory minerals (Povondra *et al.*, 1992).

Barren granitic pegmatites (iii) commonly form dikes to irregular bodies, up to 2 m thick (mostly several dm). They exhibit simple symmetrically zoned internal structure consisting of (from the border to the centre) a fine-grained granitic unit, a graphic unit and blocky K-feldspar and blocky quartz, locally with nests of albite, similar to other granitic pegmatites in the Bory pegmatite district (Duda, 1986; Staněk, 1991; Novák *et al.*, 1992). Rare pockets lined with crystals of smoky quartz, muscovite, albite, K-feldspar and locally with tourmaline, apatite (Fig. 3.3a,b), chlorite and carbonate were found in some dikes. The accessory minerals include andalusite, ilmenite, apatite, rutile, and pyrite.

Fig. 3.3. Photographs of tourmaline (a) and apatite with muscovite (b) from Horní Bory. Tourmaline crystal is 3 cm wide, apatite crystal length is 5 mm.

Rare nodules of primary Fe-Mn-Ca phosphates (graftonite, sarcopside, apatite) were exceptionally found in a single pegmatite dike, which very likely belongs to the ***more evolved pegmatites*** (iv).

3.3.4 Mineralogy

The rocks of the Horní Bory quarry contain a wide spectrum of minerals occurring in pegmatites and migmatite leucosome, Alpine veins and various metamorphic rocks. They were reported in several descriptive papers (see *e.g.*, Sekanina, 1946; Burkart, 1953 and references therein), but only sporadically studied in detail (see *e.g.*, Povondra, 1981; Staňková, 1982; Povondra *et al.*, 1992).

Cordierite

Two texturally distinct types of cordierite were found in Horní Bory. **Cordierite I** occurs in the leucosome as equidimensional aggregates or subhedral prismatic crystals, up to 5 cm in size. Fresh cordierite I is deep blue to greyish blue, but it is locally altered to a mixture of chlorite, biotite and muscovite. Rare dark greyish blue **cordierite II** occurs as fine-grained aggregates, up to 3 cm in size, in irregular melt patches randomly distributed in granulite.

Chemical composition of cordierite I published by Povondra *et al.* (1992) gave $X_{Fe} = 0.44$ and moderate content of Na_2O, up to 0.15 apfu. New EMP data yielded very similar results with $X_{Fe} = 0.4$ to 0.3 and 0.05 to 0.11 Na apfu. Cordierite II from granulite is Fe-enriched with $X_{Fe} = 0.50$ to 0.46 and 0.04 to 0.08 apfu Na. Cordierite I was studied by wet method by Povondra *et al.* (1992). They found elevated concentrations of H_2O (1.35 wt%) and CO_2 (0.50 wt%). Both H_2O I and H_2O II was found using IR study. Very low concentration of Li_2O (0.022 wt%) was observed in cordierite I.

Tourmaline

Tourmaline is present in all pegmatite types known from Horní Bory. Microscopic **tourmaline I** replaces grandidierite (**schorl**) or boralsilite (**olenite**) in (i) veinlet with grandidierite. Rare **tourmaline II (schorl**) from (ii) cordierite-bearing leucosome forms dark red-brownish grains and neeedles, up to several mm long. Tourmaline is not closely associated with cordierite I. Abundant **tourmaline III (*oxy-schorl*)** forms black subhedral prismatic crystals and aggregates, up to several cm long, chiefly enclosed in blocky K-feldspar or blocky quartz from (iii) barren granitic pegmatite, which cuts granulite facies rocks.

Individual types of tourmaline exhibit quite different composition (Povondra, 1981; Povondra *et al.*, 1992). The T-site is commonly occupied by Si (6.01 and 5.96 apfu). The Z-site is likely fully occupied by Al, but moderate ^{Y}Al (0.59 and 0.75 apfu) and Fe^{3+} (0.17 and 0.20 apfu) were found in tourmaline I and II, respectively. Contents of Ti are low ($\leq$ 0.08 apfu), and Mn is very low. Tourmaline I and II are characterized by low to moderate vacancy in the X-site (0.13 and 0.32 pfu), only slightly elevated Ca ($\leq$ 0.08 apfu) were recorded. Both tourmaline types differ significantly in the X_{Fe} (0.56 and 0.79) in tourmaline I and II, respectively. Tourmaline I and II are F-poor (both 0.14 apfu), show B content close to the stoichiometric value 3 (2.95 and 3.05 apfu), and are Li-poor (0.008 and 0.010 wt% Li_2O). They also differ in ^{W}O (0.28 and 0.63 apfu) (Fig. 3.4).

Anhydrous borosilicates

Pale green, elongated crystals of **grandidierite–ominelite**, up to 4 mm long, and radial aggregates of prismatic crystals of **boralsilite** in quartz are the major primary phases, the latter is rarely intergrown with rare **Fe analogue of werdingite**. Boralsilite also forms radial overgrowths on grandidierite. Grandidierite–ominelite crystals are frequently either rimmed by a narrow zone of tourmaline or completely replaced by the assemblage **tourmaline + corundum**, whereas associated boralsilite is usually altered into a fine-grained mixture of phyllosilicates (Fig. 3.5a,b). Exceptionally, secondary olenite after boralsilite was observed. Zoned grains and crystals of **dumortierite** were found embedded in tourmaline, together with altered boralsilite. Associated minerals include along with quartz and feldspars accessory dumortierite (locally Sb-enriched), **ferberite**, **rutile** to **niobian W-rutile**, **wolframoixiolite**, **ilmenite**, and **monazite-(Ce)**.

In zoned grandidierite–ominelite crystals X_{Fe} ranges from 0.37 (core) to 0.71 (rim), also both other primary phases – Fe analogue of werdingite (X_{Fe} = 0.68 to 0.79) and boralsilite (X_{Fe}

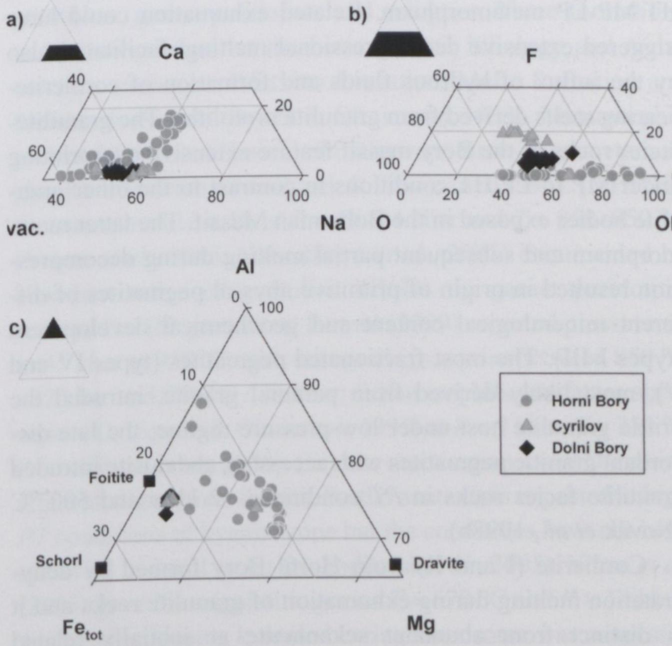


Fig. 3.4. Composition of tourmaline from Bory pegmatites.
a) X-site, b) W-site, c) Y + Z sites.

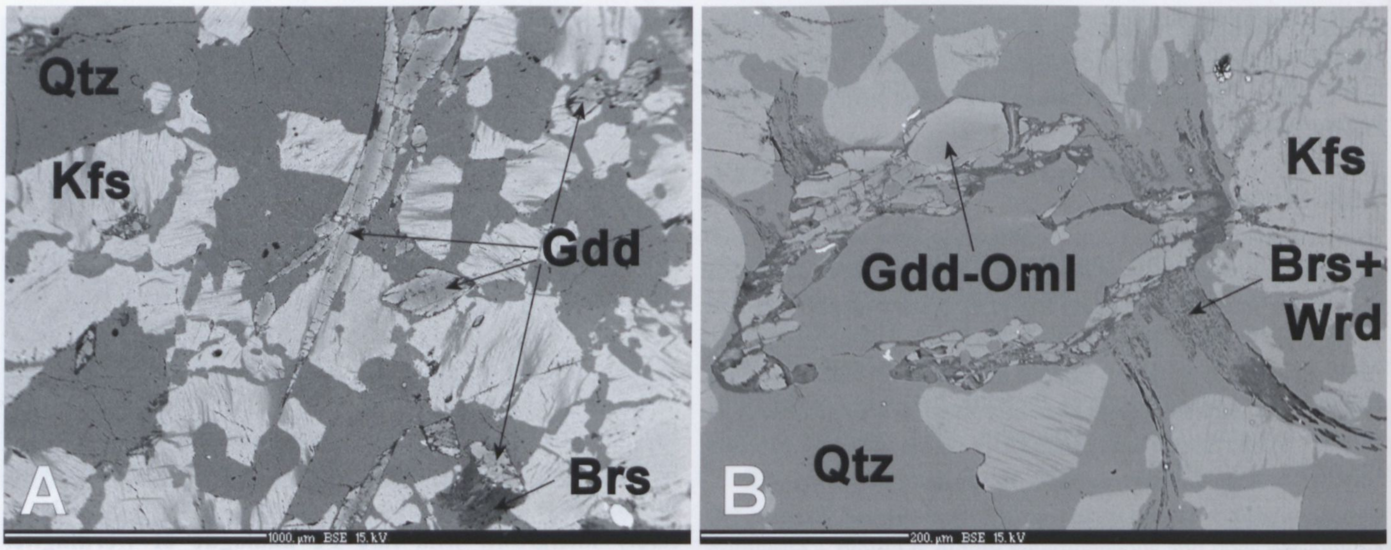


Fig. 3.5. Mineral assemblage of grandidierite–ominelite and boralsilite.

A) needles of grandidierite (Gdd) with rims of ominelite in K-feldspar (Kfs) and quartz (Qtz), locally overgrown by boralsilite (Brs). Scale bar 1 mm.
B) partly altered aggregate of boralsilite and werdingite (Brs + Wrd) overgrowing skeletal crystal of grandidierite-ominelite (Gdd-Oml), in quartz and K-feldspar. Scale bar 0.2 mm.

= 0.67 to 0.84) are Fe-rich. Chemical composition of boralsilite and werdingite suggests their partial solid solution. Tourmaline is Al-rich, with high amount of foitite and olenite components (up to 1.6 apfu $^{Y}Al_{tot}$ and 0.2 apfu ^{T}Al). It is almost F-free and significantly vacant in X-site (≤ 0.7 pfu). Tourmaline X_{Fe} ranges within that of the grandidierite–ominelite precursor (Fig. 3.6).

3.3.5 Concluding remarks

The Bory granulite massif exhibits a polyphase tectonometamorphic evolution. Granulite-facies metamorphism ($T \approx 1000$ °C, $P \approx 16$ kbar, Carswell & O'Brien, 1993) is overprinted by HT/MP-LP metamorphism. Related exhumation could have triggered extensive decompressional melting, facilitated also by the influx of hydrous fluids and formation of cordierite-bearing melts derived from granulite protoliths. The granulite-facies rocks of the Bory massif feature extensive overprinting under MP to LP/HT conditions in contrast to the other granulite bodies exposed in the Bohemian Massif. The latter metamorphism and subsequent partial melting during decompression resulted in origin of primitive abyssal pegmatites of different mineralogical content and geochemical development (types I-III). The most fractionated pegmatites (types IV and V), most likely derived from parental granite, intruded the brittle granulite host under low-pressure regime; the late discordant granitic pegmatites with accessory andalusite intruded granulite facies rocks in *PT* conditions ~2 kbar and 500 °C (Novák *et al.*, 1998b).

Cordierite (I and II) from Horní Bory formed by dehydratation melting during exhumation of granulite rocks and it is distinct from abundant sekaninaite at spatially related granitic pegmatites at Dolní Bory (Staněk, 1991). Cordierite was not found in late discordant granitic pegmatites in Horní Bory and tourmaline is a dominant Fe-Mg phase. In contrary, in the more evolved pegmatites (type IV) of Bory pegmatite district sekaninaite occurs along with tourmaline. Sekaninaite exhibits very high X_{Fe} (0.97–0.74), high Na (up to 0.26 apfu), higher concentrations of Mn (up to 0.18 apfu) but especially high amount of Li (up to 0.24 apfu) but very low Be (< 0.003 apfu) (Černý *et al.*, 1997), as compared to cordierite I and II. Presence of rare dumortierite and tourmaline in migmatite leucosome indicates locally elevated activity of B in melt sufficient for formation of tourmaline or dumortierite (*cf.* London *et al.*, 1996; Dingwell *et al.*, 1996).

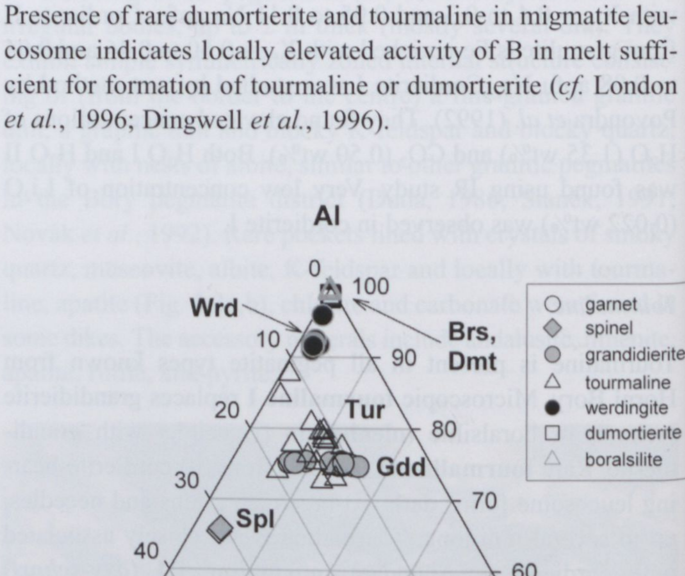


Fig. 3.6. Composition of minerals from abyssal pegmatite veinlet with grandidierite.

Grt – garnet, Spl – spinel, Tur – tourmaline, Gdd – grandidierite, Wrd – werdingite, Brs – boralsilite, Dmt – dumortierite.

3.4 Field stop 4: Starkoč near Čáslav, Kutná Hora Unit – Abyssal pegmatite of the BBe subclass

(Jan Cempírek & Milan Novák)

3.4.1 Introduction to abyssal pegmatites in the Gföhl unit, Bohemian Massif

Abyssal (metamorphic) pegmatites are related to anatectic processes in high-grade metamorphic rocks of upper amphibolite to granulite facies. Their mineral assemblages are mostly simple, including common rock-forming minerals such as muscovite, biotite, garnet, tourmaline, cordierite and Al_2SiO_5 modifications besides major minerals – quartz, plagioclase and/or K-feldspar. Abyssal pegmatites form dikes, lenses or irregular bodies commonly about several cm to several dm thick, hosted largely in metapelitic rocks. Their internal structure is commonly simple, complexly zoned pegmatites are rare. Based on the accessory minerals, the abyssal pegmatites were subdivided into four subclasses – AB-HREE, AB-LREE, AB-U and AB-BBe (Černý & Ercit, 2005).

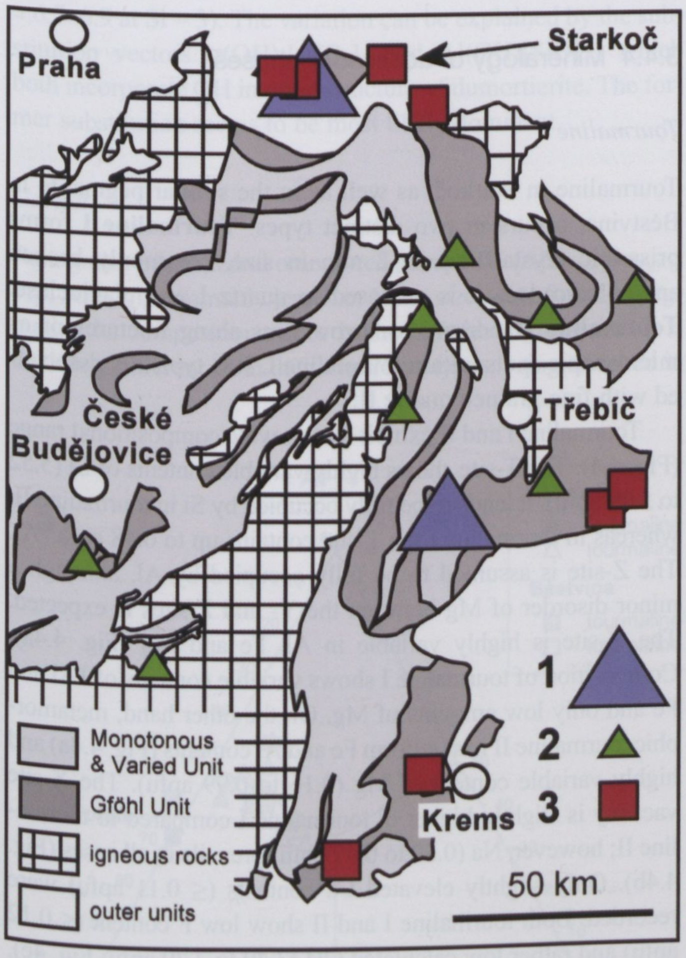


Fig. 4.1. Dumortierite occurrences in the Gföhl Unit and position of the excursion locality Starkoč (Cempírek & Novák, 2006b). *Symbols: 1 – major occurrences in boron-bearing granulites and migmatites, 2 – rare occurrences in granulites, migmatites and gneisses, 3 – occurrences in abyssal pegmatites.*

Pegmatite veinlets of the AB-BBe subclass (Fig. 4.1.) from the Moldanubian Zone are very similar in their shape, size and mineral assemblages. They are always hosted in high-grade rocks within the Gföhl Unit, particularly along the easternmost border of the Moldanubian Zone (Fig. 4.1.). Two distinct textural types of pegmatites were recognized: (i) ***discordant pegmatite veinlets***, commonly 1–3 cm thick, locally containing tourmaline and/or dumortierite as typical accessory to locally minor minerals, as well as less abundant apatite, garnet, arsenopyrite, graphite and kyanite (Kutná Hora-Turkaňk, Starkoč, Běstvina and Spačice; Fiala, 1954; Losert, 1956; Cempírek, 2003; Cempírek & Novák, 2006b). (ii) ***simply zoned pegmatite bodies***, up to 0.5 m thick, with very similar mineral assemblages including dumortierite and Al-rich tourmalines. These pegmatites are known only from the Malín Formation, at localities Miskovice and Kuklík near Kutná Hora (Fiala, 1954; Losert, 1956; Cempírek *et al.*, 2006). These zoned bodies show slightly higher degree of fractionation and textural differentiation (Cempírek & Novák, 2004b). Accessory minerals typical for the both types of abyssal pegmatites – dumortierite and tourmaline – were also found as widespread accessory minerals in ***leucocratic metapelites*** in this region (Losert, 1956; Synek & Olivierová, 1993). These rocks, however, do not exhibit such a high degree of melting and particularly melt segregation like the pegmatites examined.

3.4.2 Geology

The pegmatite from Starkoč is a typical example of abyssal pegmatites of the AB-BBe subclass (*cf.* Černý & Ercit, 2005). It is situated about 8 km NE from Čáslav, in the eastern part of the Kutná Hora Unit, Gföhl Unit. The area is covered dominantly by Cretaceous sediments (Fig. 4.2). Locality Starkoč is located in the Gföhl Unit characterized by HT/HP rocks, *e.g.* granulites, garnet peridotites and eclogites. Three formations were distinguished on the basis of their lithology and metamorphic evolution: Běstvina formation, Malín formation and Plaňany formation (Synek & Olivierová, 1993). Metamorphic rocks of the Kutná Hora Unit underwent three-stage metamorphism and deformation (Synek & Olivierová, 1993): (i) HP/HT metamorphic event D_1 at $P \approx 16–24$ kbar and $T \approx 850–950$ °C (Vrána *et al.*, 2005; Nahodilová *et al.*, 2005) documented by abundant relics of granulitic fabrics. In garnet peridotites enclosed in HP granulites, Faryad (2009) reported pressure up to 45 kbar at 950°C, with retrograde overprint between 850 °C / 32 kbar and 950 °C / 36 kbar; (ii) an amphibolite facies shear regime D_2 (Synek & Olivierová, 1993) at $P \approx 9$ kbar, $T \approx 750$ °C (Nahodilová *et al.*, 2005); (iii) late reactivation event D_3, which affected all previous fabrics. Partial anatexis is expected at high *PT* conditions of kyanite zone but the conditions have not been specified in detail so far (Nahodilová *et al.*, 2005). Vrána *et al.* (2005) gave for migmatitic gneiss $T \approx 670$ °C and $P \approx 14$ kbar. Anatexis producing kyanite-bearing leucosome was suggested to follow the event D_2 (Synek & Olivierová, 1993).

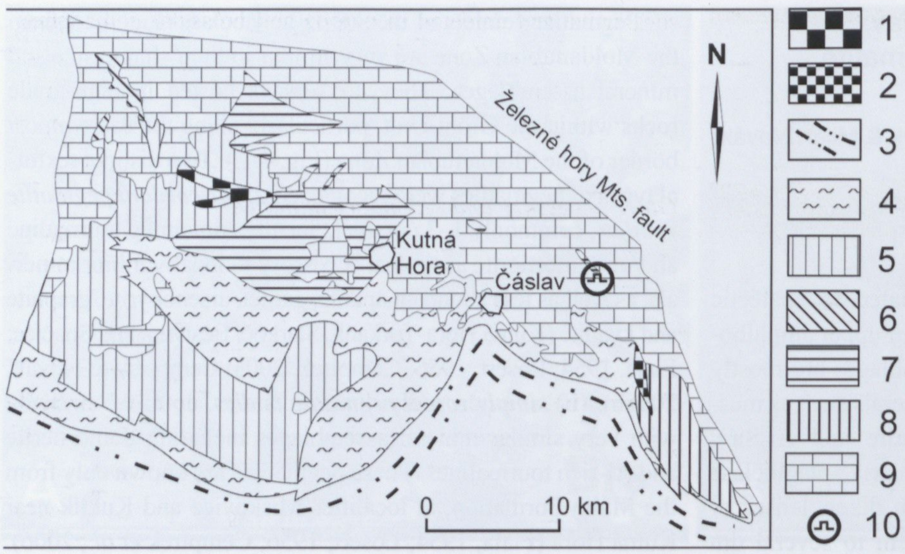


Fig. 4.2. Geological settings of the Kutná Hora Unit (modified after Synek & Olivierová, 1993).

1 – Libodřice amphibolite;
2 – Svatý kříž ultrabasic massif;
3 – contact with Moldanubian zone;
4 – Micaschist zone;
5 – Kouřim nappe;
6 – Plaňany formation;
7 – Malín formation;
8 – Běstvina formation;
9 – Cretaceous sediments;
10 – excursion locality.

3.4.3 Petrology and geochemistry of the host metapelite and pegmatite

Massive garnet-biotite gneiss to migmatite biotite gneiss contains locally large porphyroblasts of garnet enclosed in felsic leucosome. The mineral assemblage of gneiss is: quartz + plagioclase + biotite (X_{Fe} ≈ 0.47–0.49) + garnet I ($Alm_{71-68}Prp_{16-12}Sps_{14-4}Grs_{11-5}$) ± kyanite, the leucosome consists of the fine-grained assemblage: quartz + plagioclase + K-feldspar with accessory apatite, dumortierite and tourmaline. Porphyroblasts of homogeneous violet-red garnet II ($Alm_{77}Prp_{16}Sps_5Grs_2$) commonly volumetrically predominate over host leucosome. The mineral assemblages and textural relations suggest that the rock underwent several metamorphic events and deformations similar to the rocks in the Běstvina granulite (Vrána *et al.*, 2005, Nahodilová *et al.*, 2005). However, they were not studied in greater detail at the Starkoč locality.

Chemical compositions of host massive biotite gneiss and pegmatite exhibit similar concentrations of SiO_2 (71–73 wt%), Al_2O_3 (13–15 wt%), CaO (1.56–1.77 wt%) and Na_2O (2.39–3.05 wt%). They differ particularly in higher concentrations of Fe_2O_3 (5.45 *versus* 1.57–1.58), MgO (1.79 *versus* 0.20–0.35) and TiO_2 (0.74 *versus* 0.10–0.05) in host rock, and higher K_2O (2.30–2.95 *versus* 1.78) in pegmatite (all in wt%). The pegmatite is enriched in As, Ba, Ga and Sr, whereas the host rock is apparently enriched in Cs, HFSE and REE.

Locally folded pegmatite veinlet, up to 2 cm thick and several m long, cuts biotite gneiss (Fig. 4.3). It exhibits a sharp contact with the host rock. Two mineral assemblages were distinguished: (i) primary magmatic plagioclase ($Ab_{78}An_{19}Kfs_3$ – $Ab_{84}An_{15}Kfs_1$) + quartz + muscovite + tourmaline + chrysoberyl + dumortierite ± garnet formed likely before the migmatite-forming deformation phase D_2; (ii) newly-formed K-feldspar + kyanite (rarely also staurolite + quartz) replacing muscovite, related to partial melting of the assemblage muscovite + quartz (± garnet). This event also caused partial recrystallization of dumortierite and tourmaline and corrosion of chrysoberyl. Estimated conditions for the metamorphic assemblage are T ≈ 650–740 °C, P_{min} ≈ 7–8.3 kbar. The metamorphic overprint seems to be related to the amphibolite-facies deformation event D_2.

3.4.4 Mineralogy of accessory phases

Tourmaline

Tourmaline in Starkoč, as well as in the similar pegmatite in Běstvina, occurs in two distinct types. **Tourmaline I** forms prismatic crystals, up to 2 mm in size, commonly broken and/or corroded. It is enclosed in quartz I and plagioclase. **Tourmaline II** occurs as narrow rims along fractures or as microscopic spots within tourmaline I. It is typically associated with fine-grained quartz II.

Tourmaline I and II exhibit quite a wide compositional range (Fig. 4.4). The T-site shows highly variable contents of Si (5.52 to 5.99 apfu), it tends to be fully occupied by Si in tourmaline II, whereas in tourmaline I the T-site contains up to 0.48 apfu ^{T}Al. The Z-site is assumed to be fully occupied by Al, although a minor disorder of Mg between the Y- and Z-sites is expected. The Y-site is highly variable in Al, Fe and Mg (Fig. 4.4a). Composition of tourmaline I shows variable contents of ^{Y}Al and Fe and only low amounts of Mg. On the other hand, metamorphic tourmaline II has uniform Fe and Al contents (Fig. 4.4a) and highly variable content of Mg (0.16 to 0.99 apfu). The X-site vacancy is slightly higher in tourmaline I compared to tourmaline II; however, Na (0.59 to 0.49 apfu) prevails in all cases (Fig. 4.4b). Only slightly elevated Ca contents (≤ 0.11 apfu) were recorded. Both tourmaline I and II show low F content (≤ 0.12 apfu) and rather low calculated OH (3.49 to 2.79 apfu; Fig. 4c). Although the partitioning of OH between V- and W-sites is not precisely known, it is clear that tourmaline I shows a significant fraction of "oxy-tourmaline" end-member(s), whereas tourmaline II contains preferentially OH in both sites.

Fig. 4.3. Folded pegmatite veinlet from Starkoč. Thickness of the veinlet is 1-2 cm.

Dumortierite

Dumortierite I forms strongly pleochroic subhedral prismatic crystals often twinned along 110, or aggregates of needle-like or fibrous crystals, up to 3 mm long, locally associated with tourmaline I. The crystals commonly exhibit features of shearing and recrystallization. **Dumortierite II** forms colourless, needle-like to fibrous aggregates enclosed in quartz II, overgrowing corroded grains of dumortierite I or rarely tourmaline I. Dumortierite has variable but low contents of Mg (0.05 to 0.12 apfu), a uniform very low content of Fe (0.03 apfu), and traces of Ti. The dumortierite Al/Si ratio is rather variable (Al ≈ 6.7–6.9 at Si = 3). The variation can be explained by the substitution vectors $\square(OH)_3[AlO_3]_{-1}$ and $Al(OH)[SiO]_{-1}$, which both incorporate OH into the structure of dumortierite. The former substitution seems to be most likely dominant.

Garnet

Rare grains of subhedral orange-red **garnet III** ($Alm_{80-62}Sps_{30-10}Prp_{8-3}Grs_{3-2}$), commonly less than 1 mm size, were found in pegmatite. Its composition varies in the individual grains and it is distinctly different from the former two types, being enriched in spessartine and depleted in pyrope and grossular components. Minute inclusions of monazite-(Ce), xenotime-(Y) and fluorapatite were found in garnet III. During the metamorphic event, its reaction with melt probably produced rare staurolite + quartz.

Other accessory and secondary minerals

Chrysoberyl was found as a single grain about 0.1 × 0.05 mm in size, as strongly corroded crystal between grains of plagioclase, K-feldspar and tourmaline I (Fig. 4.5). Although a patchy zoning of the grain is visible in the BSE image, no chemical differences between the individual zones were detected. **Kyanite** occurs in fine-grained aggregates associated with quartz II, **K-feldspar** ($Kfs_{95-88}Ab_{5-12}$), plagioclase and rare **staurolite** (Fig. 4.6, Fig. 4.7). Minerals of this prograde metamorphic assemblage typically form irregular grains less than 50 mm in diameter, only staurolite was found as intergrowths with quartz in few grains up to 100 mm in size. Staurolite is rather poor in Mg (0.32–0.38 apfu) and rich in Fe (2.98–3.15 apfu) with variable contents of Si and Al (7.6–7.9 apfu Si, 18.5-18.0 apfu Al), concentrations of other elements are low. Rare accessory minerals include **fluorapatite**, **monazite-(Ce)** and **xenotime-(Y)** as rare inclusions in garnet III, and **löllingite.**

3.4.5 Compositional evolution of tourmaline in abyssal pegmatites

Tourmaline from abyssal pegmatites shows compositional evolution from simple schorl–dravite solid solution towards composition with significant amounts of foitite and olenite end-members (Fig. 4.8). Low contents of Ca and F (~0.1 apfu), high amounts of O^{2-} in V and/or W-sites and significantly vacant X-site are its typical features.

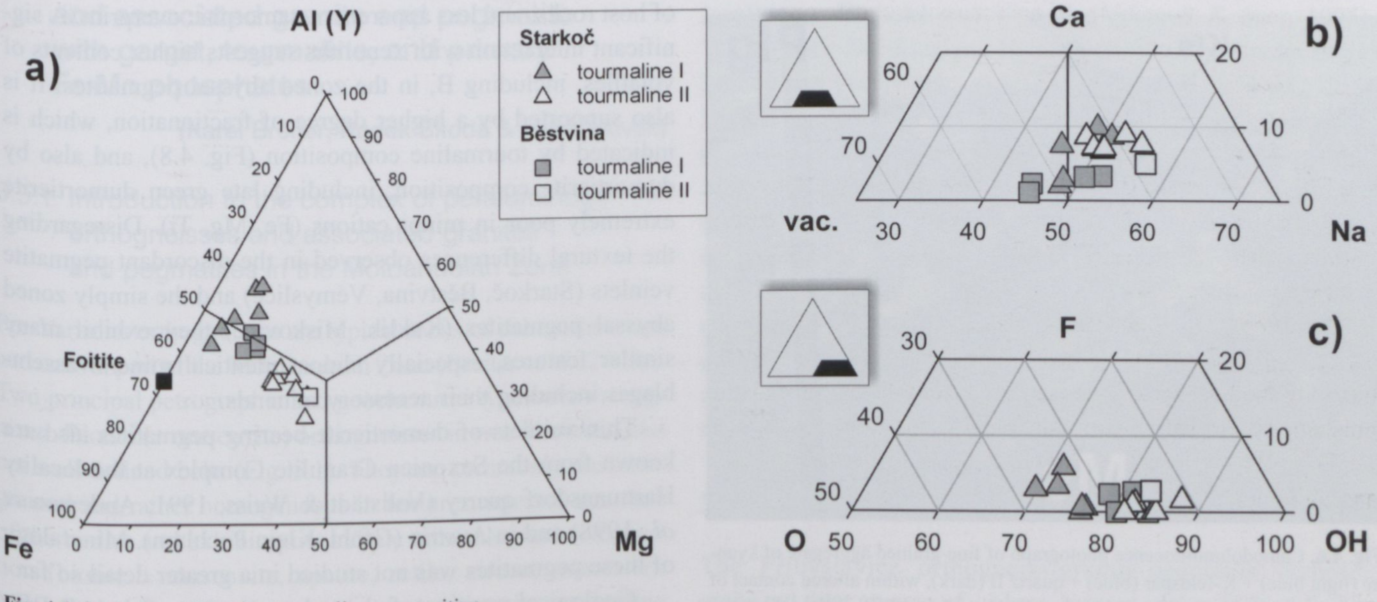


Fig. 4.4. Starkoč and Běstvina tourmaline composition.
a – Y site, b – X site, c – V + W sites (Cempírek & Novák, 2006b).

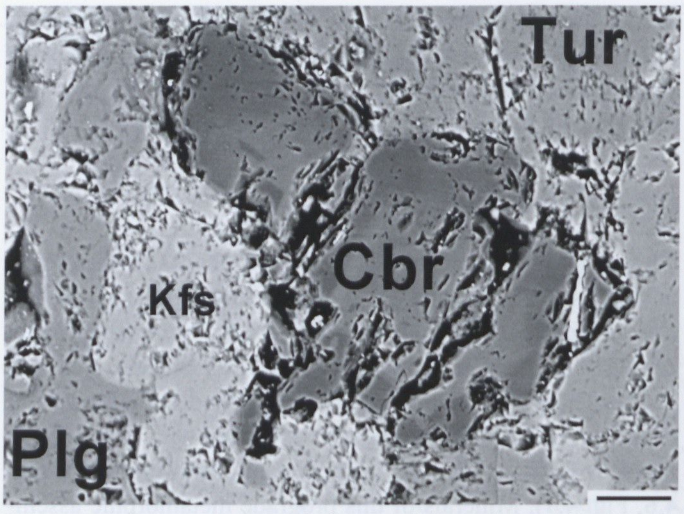


Fig. 4.5. Corroded grain of chrysoberyl (Cbr), at the contact with tourmaline I (Tur), K-feldspar and plagioclase II. Starkoč pegmatite. Scale bar is 20 mm.

Composition of tourmaline from abyssal pegmatites is commonly controlled by their two-stage origin. The primary tourmaline I is typical by its high Al-content and incorporation of Al into the T-site, whereas the secondary tourmaline has rather stoichiometric Si content in T-site. The elevated content of Al in T-site is a typical feature of tourmaline from abyssal pegmatites and very high contents of Al (up to 2.2 apfu in Y-site, up to 0.52 apfu in T-site) were found in tourmaline at other localities in the region (Miskovice, Kuklík; Cempírek, 2003; Cempírek et al., 2006). Primary tourmaline I from Starkoč and Běstvina with low variability in the X-site exhibits crystallization trend expressed by substitution vector ($^{Y,Z}Al\,^{T}Al$) ($^{Y,Z}R^{2+}\,^{T}Si^{4+}$)$_{-1}$ or by combination of vectors ($Al^{3+}OH$)(SiO^{2-})$_{-1}$ and (AlO^{2-})($R^{2+}OH$)$_{-1}$ in 1:1 ratio. Metamorphic tourmaline II is rather homogeneous and does not exhibit clear substitution trends.

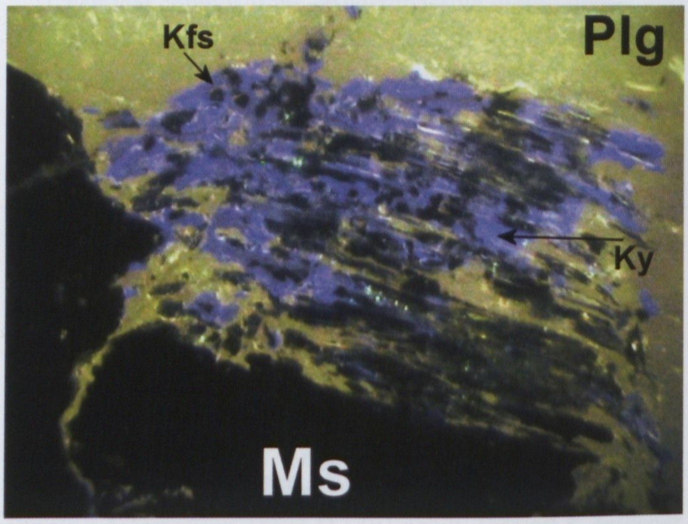


Fig. 4.6. Cathodoluminescence photograph of fine-grained aggregate of kyanite (light blue) + K-feldspar (blue) + quartz II (dark), within altered contact of muscovite crystal (black) with plagioclase II (yellow). Few grains of apatite (green) are present. Picture width is about 0.6 mm.

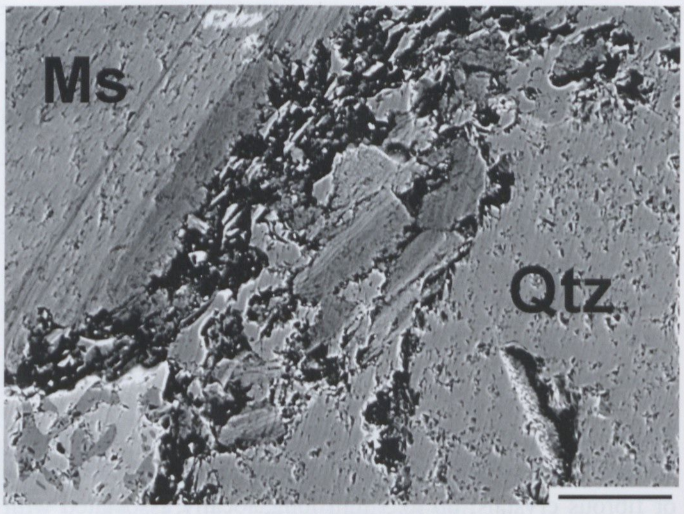


Fig. 4.7. Fine-grained aggregate of kyanite + quartz II + plagioclase II + K-feldspar, within altered rim of a muscovite crystal, at the contact with quartz I. Spotty light grain at the bottom left is staurolite with inclusions of quartz II. Darker rim of muscovite is formed by pyrophyllite. Scale bar is 50 mm.

3.4.6 Concluding remarks

The abyssal pegmatites of the AB-BBe subclass (see *e.g.* Černý & Ercit, 2005; Grew *et al.,* 2000) in Moldanubicum are typical in the presence of Al-rich minerals, close relations to HP/HT metamorphic host rock, small thickness, elevated content of light elements (B, Be), and polyphase evolution. Al-rich tourmaline and (locally As-rich) dumortierite (Cempírek & Novák, 2004a) are their typical accessories.

The most evolved abyssal pegmatites in the area, simply zoned veins from Kuklík and Miskovice (Fiala, 1954; Losert, 1956; Cempírek *et al.*, 2006) exhibit a different internal structure, but their mineralogy is similar to the simple pegmatite veinlet at Starkoč. The main differences exist in the internal structure showing zoned development, a larger thickness of pegmatite bodies, transitional contacts, presence of enclaves of host rocks, and less apparent metamorphic overprint. A significant interaction with xenoliths suggests higher contents of volatiles, including B, in the zoned abyssal pegmatites. It is also supported by a higher degree of fractionation, which is indicated by tourmaline composition (Fig. 4.8), and also by dumortierite composition, including late green dumortierite extremely poor in minor cations (Fe, Mg, Ti). Disregarding the textural differences observed in the discordant pegmatite veinlets (Starkoč, Běstvina, Vémyslice) and the simply zoned abyssal pegmatites (Kuklík, Miskovice) they exhibit many similar features, especially almost identical mineral assemblages including their accessory minerals.

Thin veinlets of dumortierite-bearing pegmatites also are known from the Saxonian Granulite Complex at the locality Hartmansdorf quarry (Vollstädt & Weiss, 1991; Anderson *et al.,* 1998) and in Austria (Gföhl, Klein Pochlarn). Mineralogy of these pegmatites was not studied in a greater detail so far.

Geological position of abyssal pegmatites of the AB-BBe subclass in the Moldanubian Zone, such as apparent HP con-

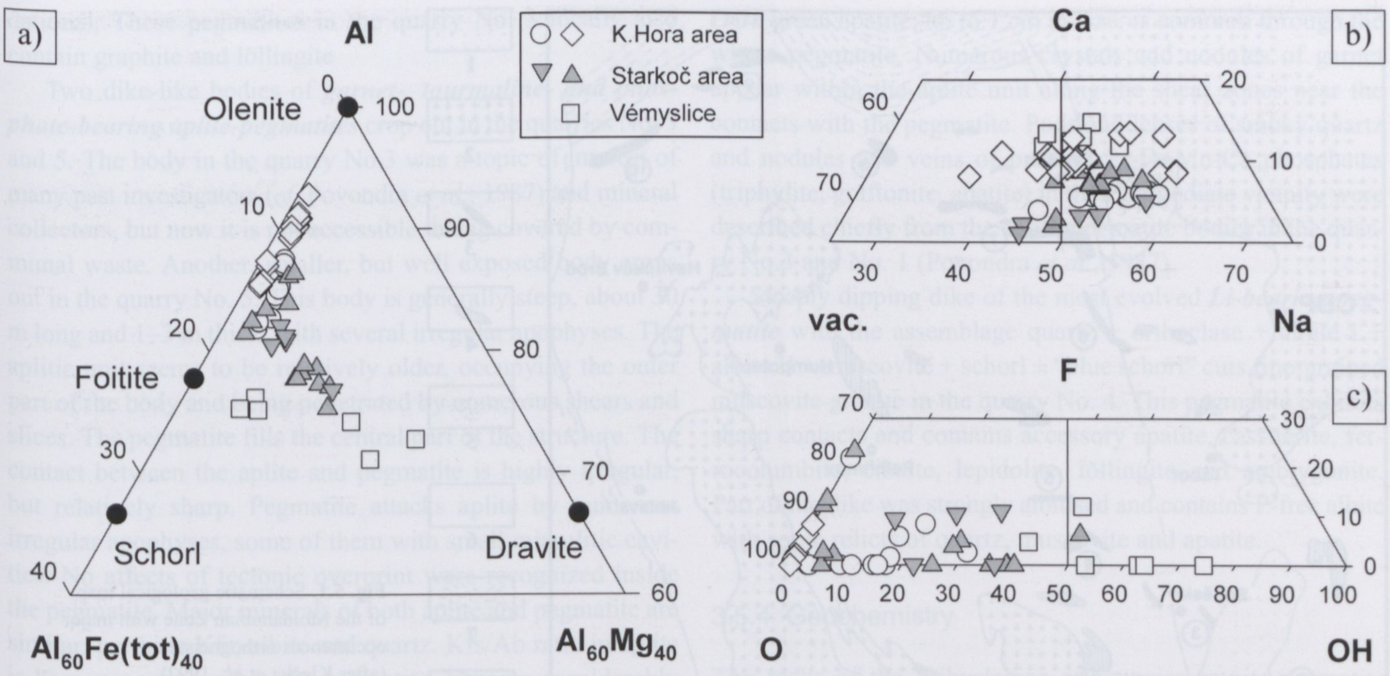


Fig. 4.8. Composition of tourmaline from abyssal pegmatites in the Gföhl unit.
a) Y + Z sites, b) X-site, c) W-site.

ditions of their origin and their absence in the other parts of the Moldanubian Zone indicate quite specific conditions necessary for the generation of this type of pegmatites. Although the individual known localities of AB-BBe subclass pegmatites in the Gföhl Unit are distant from each other, it is expected that they originated at similar PTX-conditions and during rather similar metamorphic processes.

3.5 Field stop 5: Přibyslavice near Čáslav – Complex of peraluminous phosphorus-rich tourmaline-bearing orthogneiss, and associated granite and pegmatite with garnet, tourmaline, and primary Fe-Mn phosphates

(Karel Breiter, Radek Škoda & Milan Novák)

3.5.1 Introduction to the complex of peraluminous orthogneisses and associated granites and pegmatites in the Moldanubian Zone

Pre-Variscan orthogneisses are typical rocks of the northeastern and central part of the Moldanubian Zone (Breiter *et al.*, 2005a). Two principal petrographic and geochemical types were recognized. Biotite (± muscovite) orthogneisses in two discontinuous but well-defined belts (Fig. 5.1). They are commonly medium-grained and rather homogeneous in textures, internal structure of the bodies and exhibit quite simple mineralogical composition (biotite ± muscovite, apatite, rutile, zircon, monazite). More evolved leucocratic two-mica and muscovite-tourmaline orthogneisses are more heterogeneous in textures, chemical composition and mineralogy varying from less evolved and rather homogeneous bodies (*e.g.*, Mladá Vožice) to highly evolved complex bodies with tourmaline-bearing pegmatites (*e.g.*, Blaník near Vlašim, Přibyslavice near Čáslav; Povondra *et al.*, 1987; Breiter *et al.*, 2005). Radiometric age was determined only at the Hluboká orthogneiss ($^{207}Pb/^{206}Pb$ on zircon as 508 ± 7 Ma; Vrána & Kröner, 1995), other orthogneisses were not dated and their Pre-Variscan age is derived from their evident metamorphic overprint and geological position.

Přibyslavice locality belongs to a well-defined discontinuous belt of separate orthogneiss bodies situated in the northernmost part of the Moldanubian Zone. The belt includes major localities – Hluboká nad Vltavou (Vrána & Kröner, 1995), Vlastějovice nad Sázavou, Blaník near Vlašim (Breiter *et al.*, 2005a) and Přibyslavice near Čáslav (Povondra *et al.*, 1987; Breiter *et al.*, 2003). It represents the most evolved and complex orthogneiss-granite-pegmatite system including dominant foliated tourmaline-muscovite orthogneiss locally with large crystals of garnet, nodules of primary Fe-Mn-Ca phosphates (triphylite, graftonite, apatite), fine-grained peraluminous granite, coarse-grained pegmatite facies as well as cross-cutting pegmatite dike with Li-bearing minerals (lepidolite, elbaite, amblygonite, Povondra *et al.*, 1987). Quartz veins with Sn-Nb-Ta mineralization (Breiter *et al.*, 2006) mined in a past from placers are only briefly mentioned.

3.5.2 General geology

The Přibyslavice orthogneiss-granite-pegmatite complex crops out over an area of ~3 km², located ~5 km SSE of Čáslav near the northern contact of the Moldanubicum with the Kutná

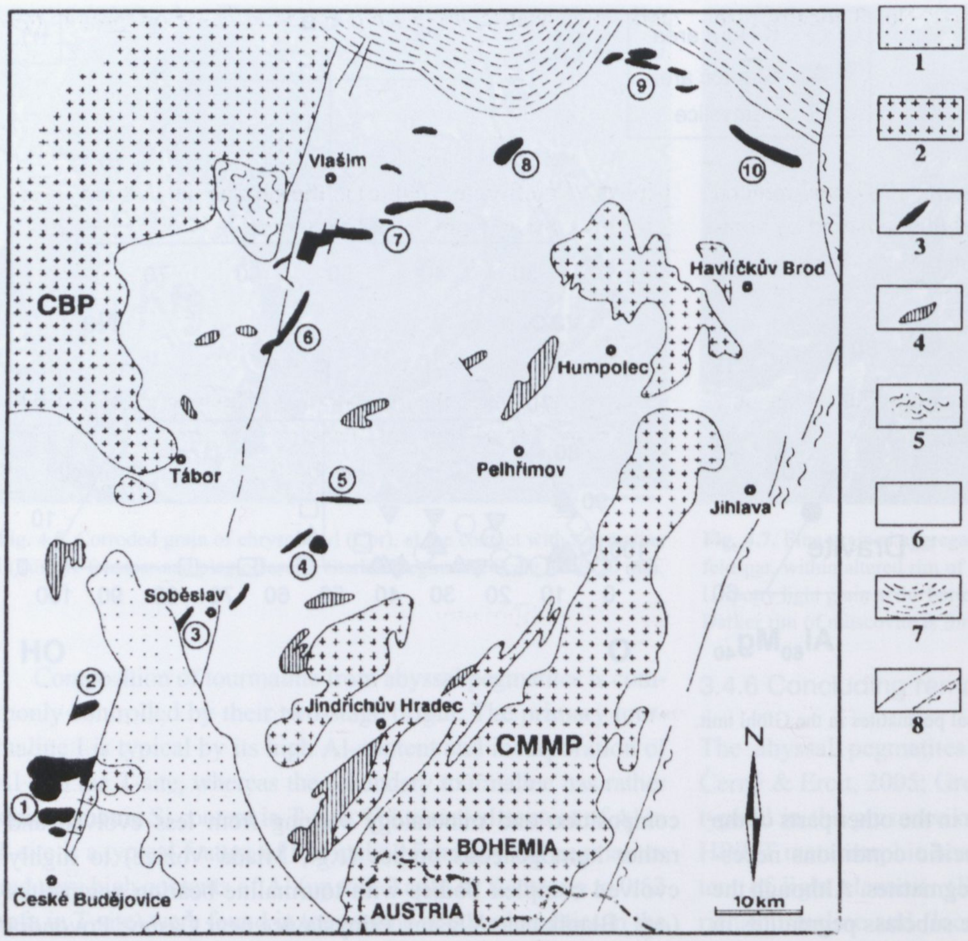


Fig. 5.1. Schematic geological map of the Moldanubian Zone with major occurrences orthogneisses (after Klečka *et al.*, 1992).
1 – Tertiary and Cretaceous sediments,
2 – Variscan granitoids,
3 – Caledonian orthogneisses of the Blaník type (Přibyslavice = no. 9),
4 – Cadomian orthogneisses,
5 – Gföhl leucocratic orthogneiss,
6 – metamorphic rocks,
7 – Kutná Hora Unit,
8 – main fault systems and mylonitic zones.

Hora Unit. The orthogneiss body is enclosed in two-mica and biotite paragneisses with sillimanite and garnet and is distinctly foliated parallel with metamorphic host rocks. Its E–W elongation is essentially parallel to the foliation of its metamorphic envelope. The central part of the orthogneiss body was intruded by a small stock (~50 m in size) of muscovite granite and several dikes of aplite-pegmatites, commonly E–W trending. Subsequent N–S trending joints divided the orthogneiss body into three blocks. The orthogneiss is cut by an E–W trending quartz vein with cassiterite-columbite mineralization (Breiter *et al.*, 2006).

The Přibyslavice body is opened by several small quarries (Fig. 5.2), which are not active from the late seventies. However, quarries No. 2, 4 and 5 still provide good outcrops of most rock types including dominant muscovite-tourmaline orthogneiss, fine-grained muscovite granite, aplite-pegmatite dike and the most evolved pegmatite dike with accessory Li-bearing minerals.

3.5.3 Petrology

The Přibyslavice orthogneiss is heterogeneous in mineral composition and textures (Povondra *et al.*, 1987; Breiter *et al.*, 2003, 2005a). The ***foliated muscovite-tourmaline orthogneiss*** is apparently dominant. It is medium- to locally fine-grained, and it can be termed a tourmaline-muscovite to muscovite-tourmaline alkali-feldspar granite. Tourmaline crystals exhibit locally a weak lineation. The main constituents of the orthogneiss are: K-feldspar (orthoclase-perthite), albite, quartz, muscovite, biotite and tourmaline. Accessory minerals include frequent apatite and garnet and rare zircon, magnetite, pyrite and ilmenite.

Fine-grained muscovite granite forms small stock open in good outcrops in the quarry No. 4. The main constituents are quartz, K-feldspar, albite (both are P-rich – 1.0–1.5 wt% P_2O_5) and muscovite. Nodules of garnet are abundant, but tourmaline is rare. Wide spectrum of accessory phases includes nodules of sillimanite, zincian staurolite, dumortierite, cassiterite, nigerite, ferroan gahnite and manganoan siderite.

Pegmatitic rocks are typical in the Přibyslavice complex and they penetrated both muscovite-tourmaline orthogneiss and muscovite granite. ***Lenticular or schlieren-like pegmatite*** bodies, up to several m long and 0.5 m thick were occasionally found within the orthogneiss. They commonly exhibit mainly blocky texture; graphic intergrowths of K-feldspar and quartz are very rare. The pegmatitic rock with the assemblage quartz + orthoclase + albite + muscovite is the most common variety. The grain size varies between 0.5 and 10, rarely up to 15 cm. Two generations of albite are locally present, tourmaline and biotite are minor but variable, garnet and apatite are relatively common. The contact of pegmatite rocks with the surrounding orthogneiss is commonly irregular, neither sharp nor truly gradational. These pegmatites in the quarry No. 3 locally also contain graphite and löllingite

Two dike-like bodies of ***garnet-, tourmaline- and phosphate-bearing aplite-pegmatites*** crop out in the quarries No. 3 and 5. The body in the quarry No.3 was a topic of interest of many past investigators (*cf.* Povondra *et al.*, 1987) and mineral collectors, but now it is not accessible, being covered by communal waste. Another, smaller, but well exposed body crops out in the quarry No. 5. This body is generally steep, about 30 m long and 1–3 m thick, with several irregular apophyses. The aplitic unit seems to be relatively older, occupying the outer part of the body and being penetrated by numerous shears and slices. The pegmatite fills the central part of the structure. The contact between the aplite and pegmatite is highly irregular, but relatively sharp. Pegmatite attacks aplite by numerous irregular apophyses, some of them with small miarolitic cavities. No affects of tectonic overprint were recognized inside the pegmatite. Major minerals of both aplite and pegmatite are similar: perthitic Kfs, albite and quartz. Kfs/Ab ratio in aplite is homogeneous, within the pegmatite domains considerably enriched in Kfs or albite were encountered. Muscovite is typical for the aplite, whereas biotite- or tourmaline-dominant domains are common in pegmatites. Tourmaline appears also in the pegmatite apophyses in aplite and in their surroundings. Dark green apatite, up to 1 cm in size, is common through the whole pegmatite. Numerous crystals and nodules of garnet appear within the aplite unit along the shear zones near the contacts with the pegmatite. Pods and lenses of smoky quartz and nodules and veins of primary Li-Fe-Mn-Ca phosphates (triphylite, graftonite, apatite) in their immediate vicinity were described chiefly from the aplite-pegmatite bodies in the quarry No.3 and No. 1 (Povondra *et al.*, 1987).

Steeply dipping dike of the most evolved ***Li-bearing pegmatite*** with the assemblage quartz + orthoclase + albite I + albite II + muscovite + schorl ± "blue schorl" cuts fine-grained muscovite granite in the quarry No. 4. This pegmatite exhibits sharp contacts and contains accessory apatite, cassiterite, ferrocolumbite, elbaite, lepidolite, löllingite and amblygonite. Part of the dike was strongly albitised and contains P-free albite with some relicts of quartz, muscovite and apatite.

3.5.4 Geochemistry

The rocks of the Přibyslavice orthogneiss-granite-pegmatite complex are leucocratic (< 1 wt% Fe_2O_{3tot}) and peraluminous (A/CNK 1.08 to 1.50) granitoids; Al oversaturation is indicated by the presence of muscovite, tourmaline, garnet, sillimanite, staurolite and gahnite. The rocks are commonly similar

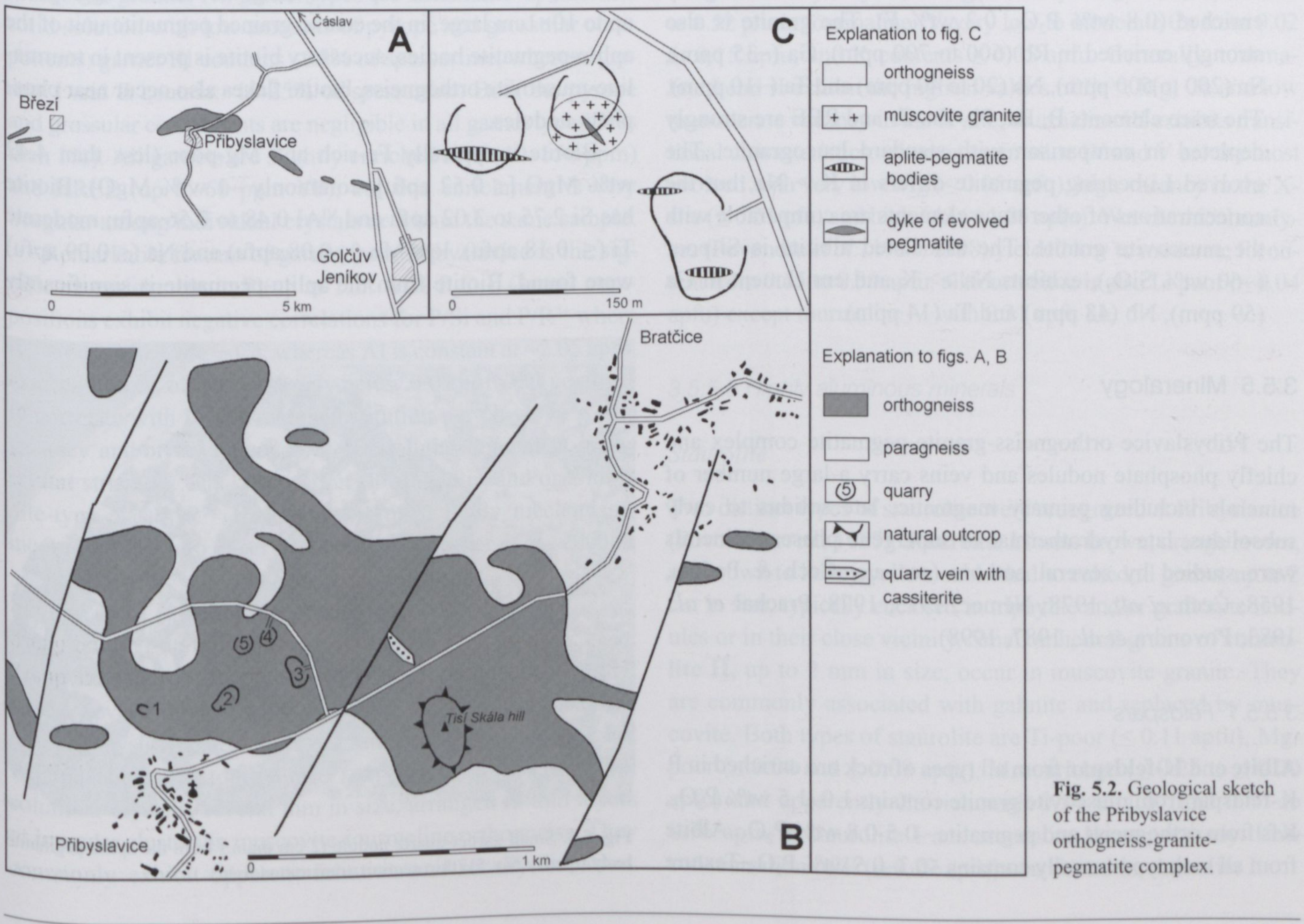


Fig. 5.2. Geological sketch of the Přibyslavice orthogneiss-granite-pegmatite complex.

also in concentrations and behaviour of trace elements. This makes the genetic interpretations difficult because the chemical composition of major oxides and trace elements can be hardly used for discrimination of individual samples into principal geological and geochemical types. Based on set of 45 chemical analyses, three groups of rock were distinguished:

1. The orthogneisses are homogeneous with SiO_2 (74 to 76), Al_2O_3 (14.5 to 15.5), Fe_2O_{3tot} (0.6 to 1.0), low MgO (< 0.1) and CaO (< 0.4) (all in wt%). The enrichment in P (0.3 to 0.5 wt% P_2O_5), F (0.1 to 0.2 wt% F), B (~0.1 wt% B_2O_3), Rb (400 to 600 ppm) and Sn (20 to 50 ppm) is typical. The elements Ba, Zr, Pb, Zn and REE are strongly depleted in comparison with standard granitoids.

2. The aplite-pegmatite rocks are the most enriched in P (0.4 to 1.5 wt% P_2O_5), Ca (0.3 to 1.5 wt% CaO) and HREE due to high content of apatite. These rocks are also enriched in Li (0.07 to 0.13 wt% Li_2O) and Ba (110 to 390 ppm). The contents of Na_2O and K_2O are highly variable due to variation of albite and K-feldspar. The concentrations of Sn, Nb and Ta are very low.

3. The muscovite granite and evolved Li-bearing pegmatite are the most fractionated rocks. In comparison with orthogneiss, the granite contains slightly less SiO_2 (~73.5 wt%), Fe, Mg, and Ca; Na > K, P and F are slightly enriched (0.8 wt% P_2O_5, 0.2 wt% F). The granite is also strongly enriched in Rb (600 to 700 ppm), Ga (~35 ppm), Sn (200 to 500 ppm), Nb (20 to 40 ppm) and Ta (~10 ppm). The trace elements B, Ba, Pb, Zn, Zr and REE are strongly depleted in comparison with standard leucogranite. The evolved Li-bearing pegmatite differs in K > Na, but the concentrations of other trace elements are comparable with the muscovite granite. The associated albitite is Si-poor (~60 wt% SiO_2), exhibits Na >> K and enrichment in Ga (59 ppm), Nb (48 ppm) and Ta (14 ppm).

3.5.5 Mineralogy

The Přibyslavice orthogneiss-granite-pegmatite complex and chiefly phosphate nodules and veins carry a large number of minerals including primary magmatic, late solidus to early subsolidus, late hydrothermal or supergene phases. Minerals were studied by several authors (see *e.g.* Čech & Paděra, 1958; Čech *et al.*, 1978; Němec, 1973, 1978; Prachař *et al.*, 1983; Povondra *et al.*, 1987, 1998).

3.5.5.1 Feldspars

Albite and **K-feldspar** from all types of rock are enriched in P. K-feldspar from muscovite granite contains 1.0–1.5 wt% P_2O_5, Kfs from orthogneiss and pegmatite ~0.5-0.8 wt% P_2O_5. Albite from all rock types usually contains ~0.3–0.5 wt% P_2O_5. Texture of feldspars from the orthogneiss, together with their high content of P (albite II from Li-bearing pegmatite is almost P-free) indicate that feldspars survived Variscan metamorphism without significant changes of composition. Content of Rb and Ba in Kfs from different pegmatite bodies well demonstrates strong geochemical evolution within a small pegmatite field.

3.5.5.2 Micas

Muscovite

The muscovite-tourmaline orthogneiss, fine-grained muscovite granite and all aplite-pegmatite and pegmatite bodies contain large flakes of muscovite as the most significant aluminous mineral. Muscovite is also common in the quartz-cassiterite vein.

Muscovite is slightly enriched in Fe and Mg and it shows Si ≤ 3.46 apfu, ^{VI}Al of 0.97 to 0.83 apfu, Fe^{2+} ≤ 0.20 apfu and Mg ≤ 0.09 apfu. The X_{Fe} in muscovite is generally lower than that in associated biotite. The concentrations of minor and trace elements vary in these intervals: 1.0 to 1.5 wt% F, 0.2 to 0.4 wt% Li_2O, 1500 to 2900 ppm Rb, 100 to 200 ppm Cs and 8150 to 300 ppm Zn. There are no distinct chemical differences among muscovite from different rock types.

Biotite

Biotite **(annite)** occurs as primary magmatic mica in aggregates, up to 10×1cm large, in the coarse-grained pegmatite unit of the aplite-pegmatite bodies, accessory biotite is present in tourmaline-muscovite orthogneiss, biotite flakes also occur near phosphate nodules.

Biotite is typically Fe-rich and Mg-poor (less than 4.42 wt% MgO [≤ 0.52 apfu], commonly ~1 wt% MgO). Biotite has Si 2.75 to 3.02 apfu and ^{VI}Al 0.48 to 0.56 apfu; moderate Ti (≤ 0.18 apfu), low Mn (≤ 0.08 apfu) and Na (≤ 0.09 apfu) were found. Biotite from the aplite-pegmatite is significantly

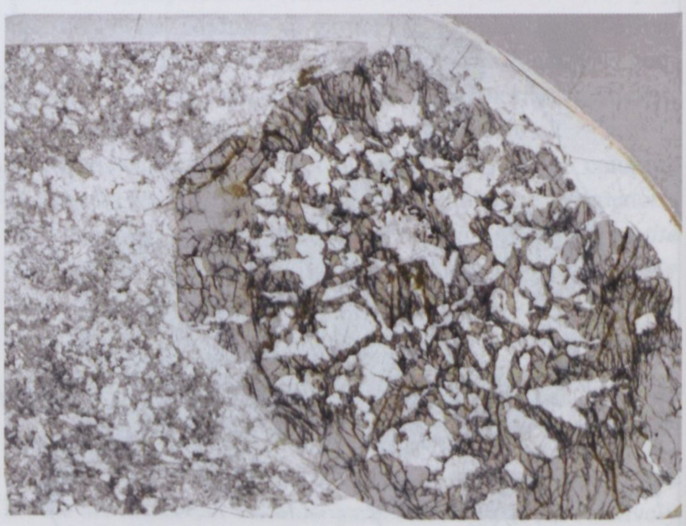


Fig. 5.3. Small garnet-quartz nodule (2 cm diam.) from the aplite-pegmatite body (quarry No. 5) (thin section, transmitted light)

enriched in light elements (up to 1.5 wt% Li_2O and 2.5 wt% F), whereas fine-grained biotite from the albitic unit shows slightly lower values (1.2 wt% Li_2O and 1.5 wt% F). Biotite from orthogneiss is relatively Li- and F-poor (~0.4 wt% Li_2O and ~1 wt% F). Elevated amounts of Rb (up to 350 ppm), Cs (up to 1900 ppm) and Zn (up to 1400 ppm) are typical.

Lepidolite

Lepidolite was mentioned in the Li-bearing pegmatite (Povondra *et al.*, 1987) but no data of its mineral assemblage and chemical composition are available. Lepidolite was found in small pebbles (Šrein *et al.*, 2004) about 200 m from the Tisá skála. It is closely associated with massive quartz and with rare grains of manganocolumbite. Its composition is close to that of **trilithionite** with elevated contents of Li (4.67 wt% Li_2O), Rb (1.71 wt% Rb_2O) and Cs (0.20 wt% Cs_2O).

3.5.5.3 Garnet

Garnet was studied in detail by Povondra *et al.* (1987) and Breiter *et al.* (2005b). Three types of **almandine**-dominant garnet were distinguished: garnet I in orthogneiss – small (≤ 5 mm) crystals; garnet II in pegmatite-aplite bodies – from mm-sized crystals to quartz-almandine nodules up to 10 cm across (Fig. 5.3); garnet III in quartz-garnet nodules several cm across in muscovite granite. All garnet types are almandine–spessartine solid solution with low amounts of pyrope and grossular components: garnet III contains ~35% of spessartine, whereas garnets I and II contain ~15-25% of spessartine. Both the pyrope and grossular components are negligible in all garnet types (less than 1%). All garnets are slightly enriched in Y (40–150 ppm) and HREE (up to 60 ppm Yb), but this enrichment is very irregular among individual crystals or within the same sample.

Remarkable feature of garnet from Přibyslavice is the significant enrichment in P (up to 1.21 wt% P_2O_5). Garnet compositions exhibit negative correlations for P/Si and P/R^{2+} where R^{2+} = Fe + Mn + Mg + Ca, whereas Al is constant at ~2.05 apfu. Concentrations of Na are largely below 0.02 apfu but positively correlate with P. The main substitution may involve A-site vacancy and/or the presence of some light element(s) in the crystal structure. The substitution $\square P_2 R^{2+}_{-1} Si_{-2}$ and/or allaudite-type $Na\square P_3 R^{2+}_{-2} Si_{-3}$ seem the most likely mechanisms incorporating P into the crystal structure (Breiter *et al.*, 2005b).

3.5.5.4 Tourmaline

Tourmaline was studied in detail by Povondra *et al.* (1987, 1998). Several distinct types of mainly black tourmaline occur in the Přibyslavice orthogneiss, granite and pegmatitic facies. The most abundant tourmaline I (***oxy-schorl***) forms subhedral columnar crystals, several mm in size, arranged in thin layers or irregular clusters in muscovite-tourmaline orthogneiss. They commonly exhibit apparent foliation and locally lineation. Tourmaline II (***oxy-schorl*, schorl**) occurs as medium- to coarse-grained aggregates in the "hybrid orthogneiss" around amphibolite xenoliths. Large columnar crystals of black tourmaline III (***oxy-schorl***), up to 3 cm long, were found associated with garnet in pegmatitic facies of aplite-pegmatite dikes. Tourmaline IV (schorl, foitite) occurs as a rare accessory mineral in fine-grained muscovite granite associated with sillimanite and dumortierite. Large columnar crystals of black to bluish black tourmaline V (***oxy-schorl***), up to 4 cm long, were found in the most evolved Li-bearing pegmatite dike. Rare green and pink **elbaite** were found in this dike but not analysed (Povondra *et al.*, 1987).

All types of tourmaline exhibit similar chemical compositions (Fig. 5.4; Povondra *et al.*, 1987, 1998). Electron microprobe study of tourmaline I and tourmaline II revealed a weak to moderate simple zoning of tourmaline grains; tourmaline III and V were analyzed solely by a wet method. The T-site is almost fully occupied by 5.83 to 6.02 apfu Si; the Z-site is likely fully occupied by Al. Low to moderate amounts of Fe^{3+} from 0.00 to 0.43 apfu were found. Highly variable ^{Y}Al varies from 0.06 apfu in tourmaline II up to 1.06 apfu in tourmaline V. All compositions derived from wet analyses correspond to schorl (*oxy-schorl*) with Mg 1.05 to 0.05 apfu, zoned tourmaline II exhibits 0.27 in core to 0.66 apfu Mg in rim. The same style of zoning, but much more restricted, was found in tourmaline I (Povondra *et al.*, 1998). The contents of Ti and Mn are usually low to moderate ≤ 0.17 apfu, and ≤ 0.05 apfu, respectively. Tourmaline is characterized by very low to high vacancy in the X-site from 0.15 to 0.52 pfu in tourmaline IV, very low to moderate Ca from 0.02 to 0.15 apfu, and K contents ≤ 0.05 apfu. Generally, tourmaline I and II exhibit the highest values of Fe^{3+}, Mg, Ca and low to moderate vacancy in the X-site, tourmaline III exhibits transitional characteristics, whereas tourmaline IV and V are the most evolved with very low Mg (≤ 0.05 apfu), high vacancy in the X-site (≤ 0.51 pfu) and high ^{Y}Al (> 1.05 apfu). Wet chemical analyses (Povondra *et al.*, 1987, 1998) yielded low to moderate F content from 0.15 to 0.39 apfu, all tourmaline is also Li poor (≤ 0.04 apfu) except tourmaline V with 0.31 apfu Li.

3.5.5.5 Highly aluminous minerals

Staurolite

Two distinct types of staurolite were recognized at Přibyslavice (Povondra *et al.*, 1987). **Staurolite I** forms brown, orange brown, red brown to honey yellow subhedral to euhedral grains, up to 2 cm in size, typically enclosed in triphylite and/or graftonite nodules or in their close vicinity. Small anhedral grains of **staurolite II,** up to 2 mm in size, occur in muscovite granite. They are commonly associated with gahnite and replaced by muscovite. Both types of staurolite are Ti-poor (≤ 0.11 apfu), Mg-poor (≤ 0.04 and ≤ 0.08 apfu), Mn-enriched (≤ 0.25 to ≤ 0.20 apfu) and apparently Zn-rich with 0.54 to 1.07 and 0.47 to 0.76 apfu in staurolite I and staurolite II, respectively. Low concentration of F (≤ 0.27 apfu) was found in staurolite I.

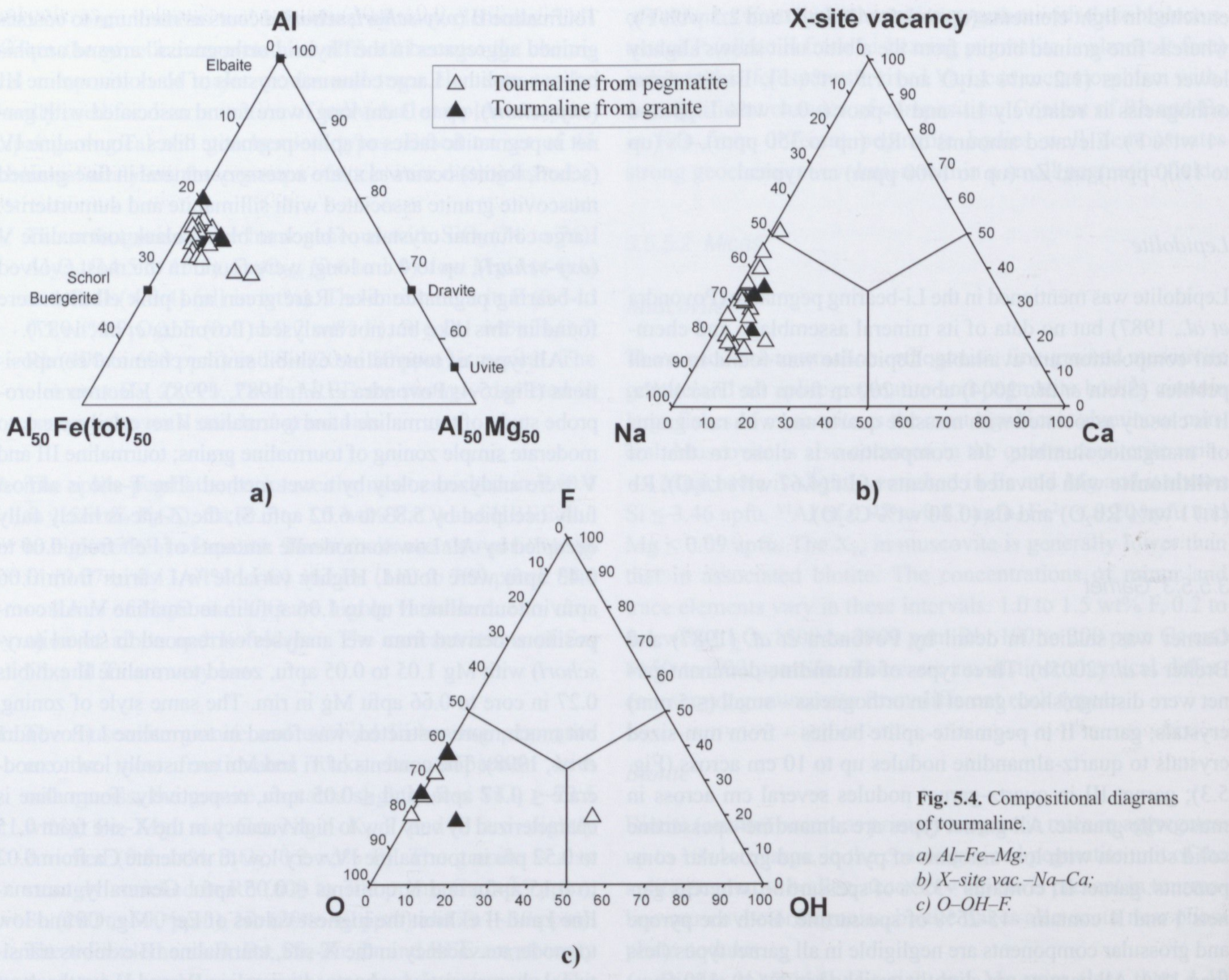


Fig. 5.4. Compositional diagrams of tourmaline.
a) Al–Fe–Mg;
b) X-site vac.–Na–Ca;
c) O–OH–F.

Dumortierite

Light blue to light violet **dumortierite** occurs exclusively in muscovite granite in the quarry No. 4 as columns or needle-like aggregates, up to 2 mm in size, within **sillimanite** nodules and aggregates. Dumortierite replaced fibrolitic sillimanite and it is partly replaced by muscovite. It is very poor in Mg and Ti and contains low Fe (≤ 0.06 apfu). The Al/Si ratio is higher than that in the ideal formula, which indicates substitution of Al in tetrahedral position.

Gahnite

Gahnite was found in three distinct paragenetic types. **Gahnite I** occurs in the muscovite granite as small, green, subhedral grains commonly ~1 mm in size. It appears relatively young replacing apatite. Microscopic intergrowths of **gahnite II** and nigerite also sporadically occur in muscovite granite. **Gahnite III** is closely associated with primary Fe-Mn phosphates and **sphalerite** as dark green grains up to 2 cm in size (Povondra *et al.*, 1987). Along with staurolite, sphalerite and nigerite, gahnite is another Zn-bearing mineral in the muscovite granite documenting late Sn,Zn-bearing postmagmatic hydrothermal activity.

Nigerite

It is only rarely found in the muscovite granite in the quarry No. as dark brown tabular crystals, up to 4×4×1 mm in size, with intensive lustre. Nigerite rarely forms intergrowths with gahnite. Chemical composition indicates 6N6S polysome. The content of högbomite molecule does not exceeds 21 mol%. Nigerite is rich in Zn, the Zn/(Zn + Fe) ratio varies from 0.51 to 0.54, which correspond to the mineral **"zinconigerite-6N6S"** (not approved by IMA, see Armbruster, 2002).

3.5.5.6 Phosphates

Fluorapatite

Apatite is a common accessory mineral, 0.X mm in size, and together with K-feldspar it is the main P-carrier in all rock types. Larger grains of green apatite (up to 5 mm) were found in some parts of aplite-pegmatite body in quarry No. 5. Apatite from muscovite granite and from some orthogneiss samples is strongly enriched in Mn and Fe (Fig. 5.5), which corroborates the evolved nature of these rocks.

Fe-Mn phosphates

The aplite-pegmatite body in quarry No. 3 supplied interesting phosphate samples in the past. Phosphate accumulates to irregular lenses, nests, and schlieren as well as thin veinlets, often rimmed by quartz, up to 30 cm in size. **Triphylite**, **sarcopside**, **graftonite** and primary fluorapatite are the main constituents of phosphate accumulations, but greenish gray triphylite is the most widespread. Tiny spindle-like lamellae of **sarcopside** in triphylite were formed by unmixing from a precursor. Subordinate light brown graftonite is usually irregularly distributed in triphylite (Povondra *et al.*, 1987).The Mn/(Mn + Fe) ratio of triphylite (0.16–0.18) is similar to that of sarcopside (0.17–0.19).

Leaching of Li from triphylite produced **ferrisicklerite** and **heterosite** whereas sarcopside lamellae remained unaltered. The hydratation and oxidation processes produced a rich assemblage of secondary phosphates including *e.g.*, **ferroalluaudite**, **lipscombite**, **ludlamite**, **melonjosephite**, **messelite**, **mitridatite**, **phosphophyllite**, **rockbridgeite**, **strunzite**, and **vivianite** (see Povondra *et al.*, 1987).

3.5.5.7 Cassiterite and Nb-Ta-Ti oxide minerals

They are present in several distinct paragenetic types but typically as small black grains mostly ≤ 1 mm in size (Povondra *et al.*, 1987; Vížďa, 2003; Breiter *et al.*, 2006). Very rare **niobian rutile I** (≤ 21.40 wt% Nb_2O_5 and ≤ 8.58 wt% Ta_2O_5) is present in aplite-pegmatites. The Li-bearing pegmatite dike contains isometric grains of brown **cassiterite I** (≤ 2.37 wt% Nb_2O_5 and ≤ 1.42 wt% Ta_2O_5) with small inclusions of **ferrocolumbite** to **manganocolumbite I** (Mn/(Fe + Mn) = 0.02–0.52, Ta/(Nb + Ta) = 0.14–0.22). **Ferrocolubite II** -0.28(Mn/(Fe + Mn) = 0.28–0.28, Ta/(Nb + Ta) = 0.01–0.06) inclusions occur also in **cassiterite II** (≤ 1.82 wt% Nb_2O_5 and ≤ 0.20 wt% Ta_2O_5) from granite associated with tiny inclusions (≤ 3 μm) of **tungstenite** WS_2. **Manganocolumbite III** from pebbles of lepidolite is Mn-rich with (Mn/(Fe + Mn) = 0.91–0.88 and Ta/(Nb + Ta) = 0.19–0.32. An ore-bearing quartz vein cut leucocratic muscovite-tourmaline orthogneiss (Breiter *et al.*, 2006). The vein is composed of smoky and milky quartz, muscovite, tourmaline; fine-grained **cassiterite III** with **ferrocolumbite IV** inclusions and **tantalian rutile II** (≤ 10.48 wt% Nb_2O_5 and ≤ 18.67 wt% Ta_2O_5) occurs in the ore vein (Fig. 5.6). Cassiterite III is Nb,Ta-rich (≤ 5.41 wt% Nb_2O_5 and ≤ 1.60 wt% Ta_2O_5) and associated ferrocolumbite IV is Mn-poor (Mn/(Fe + Mn) = 0.1–0.2) and Ta-poor (Ta/(Nb + Ta) = 0.05-0.35).

3.5.5.8 Zircon

Zircon is a common accessory mineral of orthogneiss and granite. It forms small (≤ 50 μm) partly metamict crystals, some of them enriched in the xenotime component. Zircon from granite is more fractionated (Zr/Hf = 25–32) than those from orthogneiss (Zr/Hf = 29–68). Detrital zircon from neighbouring paragneisses has Zr/Hf = 71–89.

3.5.6. Concluding remarks

The Přibyslavice orthogneiss-granite-pegmatite system is a unique example of moderate to highly evolved granitic rocks, which originated in a very long period. Although radiometric dating is absent, geological data indicate the following evolutionary model: upper-Cambrian (?) intrusion of leucocratic B-rich melt and crystallisation of muscovite-tourmaline granite → Variscan deformation and metamorphism in amphibolite-facies conditions (transformation of granite into orthogneiss) → intrusion of small aplite-pegmatite bodies closely following the latest stage of deformation → intrusion of fine-grained muscovite granite → intrusion of highly evolved Li-bearing

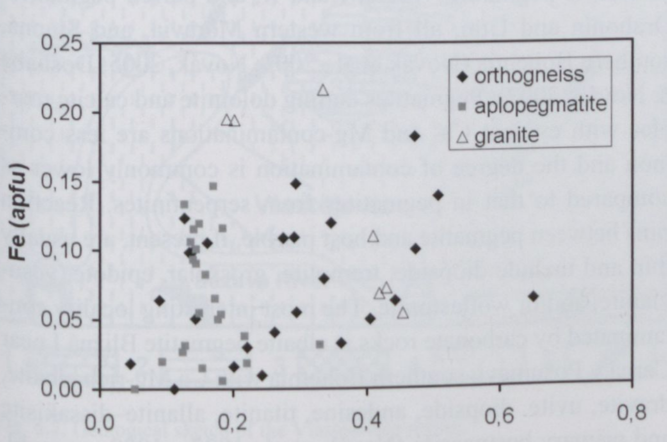


Fig. 5.5. Contents of manganese and iron in fluorapatite from Přibyslavice.

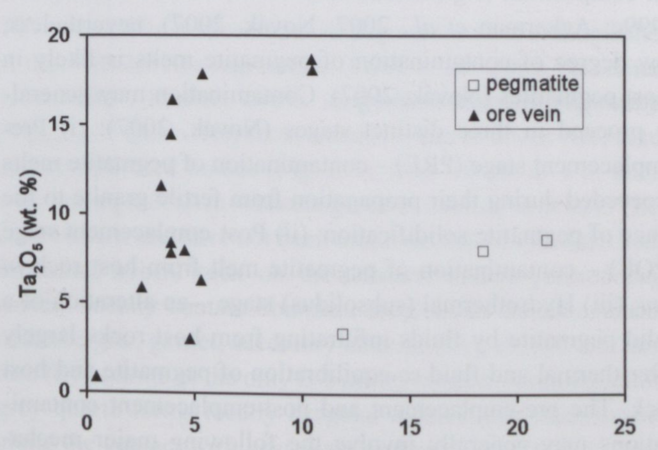


Fig. 5.6. Contents of Nb and Ta oxides in rutile from Přibyslavice.

pegmatite crosscutting muscovite granite → hydrothermal activity – quartz veins with Sn-mineralization, albitization II (very low concentrations of P).

High concentrations of B and P, moderate concentration of Li and mostly low concentration of F in various granitic rocks are of magmatic origin. The relative effects of metamorphic processes on the composition of the individual minerals of the orthogneiss, however, remain an open question. Refractory tourmaline likely underwent minor or negligible compositional changes, whereas muscovite and biotite compositions were probably reset by subsequent metamorphism. The other rocks are not affected by metamorphism, consequently, they may exhibit original magmatic compositions. Tourmaline, micas and other minerals suggest only low to moderate activity of F, but high activity of B (tourmaline, dumortierite), high activity of P (abundant primary phosphates, high P_2O_5 in garnet and in feldspars) and locally high activity of Li (triphylite, elevated Li in some tourmaline and micas). Nevertheless, the degree of fractionation *e.g.*, Fe/(Fe + Mn), Nb/(Nb + Ta) are generally low to moderate. High Fe/(Fe + Mn) values chiefly in garnet may have been controlled by the crystallization of abundant early Mn-rich apatite, which exhausted the major part of Mn from the melt and the associated garnet does not attains high Mn-content, as it is common in evolved pegmatite.

3.6 Field stop 6: Vlastějovice near Zruč nad Sázavou – Contaminated anatectic pegmatites and tourmaline-bearing granite-pegmatite system cutting Fe-skarn

(Milan Novák & Tomáš Kadlec)

3.6.1 Introduction to contaminated pegmatites in the Moldanubian Zone

Contamination from a host rock is a common feature of many granitic pegmatites. It is evident particularly in those pegmatites, which are enclosed in rocks with contrasting chemical composition (*e.g.*, Martin-Izad *et al.*, 1995; Novák *et al.*, 1999c; Ackerman *et al.*, 2007; Novák, 2007), nevertheless, low degree of contamination of pegmatite melts is likely in most pegmatites (Novák, 2007). Contamination may generally proceed in three distinct stages (Novák, 2007): (i) Pre-emplacement stage (PRE) – contamination of pegmatite melts proceeded during their propagation from fertile granite to the place of pegmatite solidification; (ii) Post-emplacement stage (POE) – contamination of pegmatite melt from host rock *in situ*; (iii) Hydrothermal (subsolidus) stage – an alteration of a solid pegmatite by fluids infiltrating from host rocks largely after thermal and fluid re-equilibration of pegmatite and host rock. The pre-emplacement and post-emplacement contaminations may generally involve the following major mechanisms: assimilation (dissolution) of fragments of solid rocks in pegmatite melt followed by more or less perfect homogenization of such contaminated melt, and infiltration (diffusion?) of fluids from host rocks into pegmatite melt.

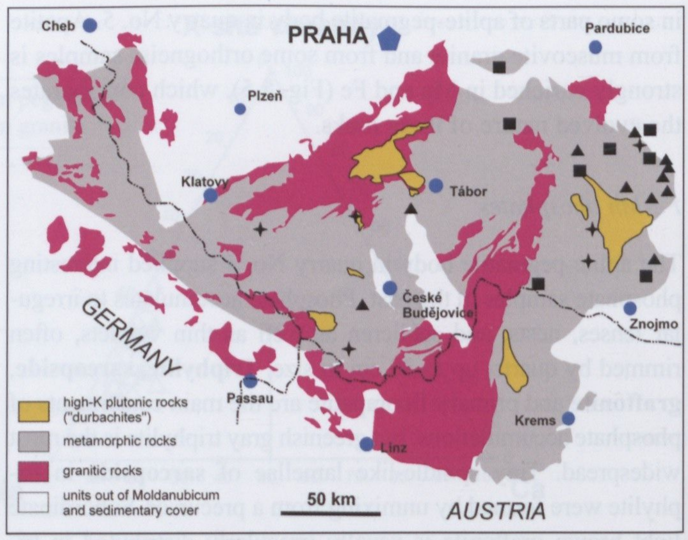


Fig. 6.1. Schematic geological map of the Moldanubian Zone with major occurrences of contaminated pegmatites, crosscutting skarns (squares), serpentinites (triangles) or marbles (stars).

Granitic pegmatites in the Moldanubian Zone are very illustrative to demonstrate contamination of granitic pegmatites because they quite commonly cut rocks with highly contrasting chemical compositions. Pegmatites cutting serpentinite with evident Mg- and minor Ca-contaminations are the most abundant. They commonly form small bodies with thick reaction rims composed of anthophylite, actinolite, phlogopite, chlorite and/or vermiculite. Oligoclase is a dominant mineral in these pegmatites, whereas quartz and chiefly K-feldspar are minor, rare to absent. Quartz is commonly at least partly dissolved or replaced by clay minerals (*e.g.*, Dosbaba & Novák, 2007). Additional primary minerals include biotite, cordierite, and tourmaline – all typically Mg-rich. Widespread late hydrothermal alteration processes produced prehnite, scapolite, carbonates, clay minerals and zeolites (see Table 1). Typical localities of contaminated pegmatites include beryl-columbite pegmatites Věžná I and II, and barren pegmatites Drahonín and Utín, all from western Moravia, and Stupná, southern Bohemia (Novák et al., 2003; Novák, 2005; Dosbaba & Novák, 2007). Pegmatites cutting dolomite and calcite marbles with evident Ca- and Mg-contaminations are less common and the degree of contamination is commonly lower as compared to that in pegmatites from serpentinites. Reaction rims between pegmatite and host marble, if present, are usually thin and include diopside, tremolite, grossular, epidote, vesuvianite, and/or wollastonite. The most interesting locality contaminated by carbonate rocks is elbaite pegmatite Bližná I near Černá v Pošumaví, southern Bohemia with Ca,Mg-rich elbaite, dravite, uvite, diopside, andesine, titanite, allanite–dissakisite and primary bastnaesite (Novák *et al.*, 1997a, 1999c; unpubl. data of the authors). Pegmatites cutting Fe-skarn with Ca-, Fe-, F- and REE-contaminations are also quite common and they are known from several localities such as Rešice and Líšná, western Moravia and chiefly from Vlastějovice nad Sázavou, central Bohemia (Vavřín, 1962; Žáček *et al.*, 2003; Ackerman *et al.*, 2007; Kadlec, 2007; Novák, 2007), where well-exposed, numerous pegmatite dikes with dominant oligoclase, amphibole, biotite, fluorite, and allanite, and less common tourmaline-bearing pegmatites occur in a large quarry. Barren pegmatites typically exhibit much higher degree of contamination as compared to more evolved beryl and complex pegmatites (Novák, 2007). Representative occurrences of contaminated pegmatites in the Moldanubian Zone are given on Fig. 6.1 to manifest their distribution and abundance within the Moldanubian Zone.

Tourmaline-bearing granite-pegmatite system at Vlastějovice represents a unique example, where pegmatites are derived directly from their fertile granite and they are moderately contaminated from host Fe-skarn. Amphibole-bearing pegmatites of anatectic origin, abundant in Fe-skarn, are discussed in contrast to demonstrate their higher degree of contamination. Chemical compositions of selected minerals – indicators of contamination – from both types of contaminated pegmatites are briefly discussed as well as the geological position of the pegmatites.

3.6.2 Geological setting

The locality Vlastějovice is situated in the Ledeč-Chýnov belt of Variegated Group (Drosendorf terrane), Moldanubian Zone (Fig. 6.2). Dominant two-mica to locally migmatized biotite-sillimanite gneisses contain common intercalations of amphibolite, pyroxene gneiss, quartzite, marbles, and common two-mica tourmaline-bearing orthogneisses. Several lenticular bodies of Fe-skarns, up to several tens m thick and several hundreds m long, occur in the NE–SW trending synclinal structure at Vlastějovice. Small bodies of leucocratic granites and simple tourmaline-bearing pegmatites with garnet (*e.g.*, Březina, Nosatá skála; Kadlec, 2007) are common in this region as well. The Fe-skarn body is highly heterogeneous and consists of: skarn *s.s.* – monomineralic massive garnetites and banded garnet-clinopyroxene (andradite-grossular + hedenbergite-diopside + magnetite ± allanite); clinopyroxene-garnet-epidote rock; lenses of massive magnetite, up to several m thick; and minor hybrid rock (hastingsite + almandine + biotite + quartz + K-feldspar + plagioclase) located between Fe-skarn and surrounding gneisses. These Fe-skarns were regionally metamorphosed at the conditions $T \approx 590$–680 °C and $P \approx 4.5$-6.5 kbar corresponding to the main Variscan metamorphic event (Žáček, 1997).

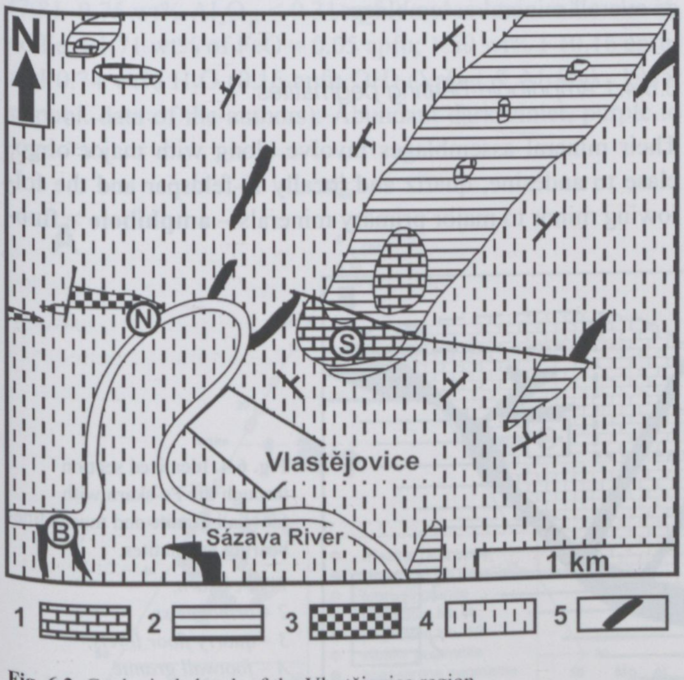


Fig. 6.2. Geological sketch of the Vlastějovice region.

1 – Fe-skarn, 2 – orthogneiss, 3 – calc-silicate rock, 4 – biotite paragneiss, locally migmatized, 5 – amphibolite. B – Březina, N – Nosatá skála, S – Holý vrch (modified from Koutek, 1950).

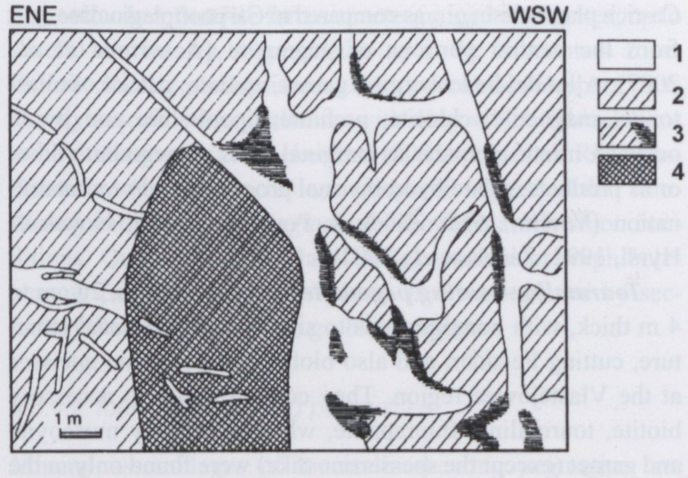


Fig. 6.3. Amphibole-bearing pegmatites cutting Fe-skarn.

1 –amphibole-bearing pegmatite, 2 – Fe-skarn, 3 – contact rock with abundant hornblende, 4 – massive magnetite (from Novák & Hyršl, 1992).

3.6.3 Amphibole-bearing pegmatites and the tourmaline-bearing granite-pegmatite system

Two principally distinct types of pegmatites were distinguished at the Vlastějovice region (see Žáček *et al.*, 2003; Ackerman *et al.*, 2007; Kadlec, 2007). ***Amphibole-bearing pegmatites*** ($Plg_{An0-35} > Qtz > Kfs$) form numerous (up to about 100) dikes and complicated bodies (Fig. 6.3), from 10 cm to 1 m thick, with homogeneous to subhomogeneous internal structure. They cut Fe-skarn and have not been found outside of the skarn body including hybrid rock on the contact. Coarse-grained pegmatites locally contain abundant amphibole, fluorite, biotite, hedenbergite, garnet, accessory allanite-(Ce), titanite and very rare ferroaxinite as the only B-bearing mineral. Monomineralic grey quartz forms locally irregular masses and veins located along the contact with host skarn and enclosing its fragments. Abundant reaction rims (Fig. 6.3), up to 30 cm thick, consist of dominant amphibole and locally also fluorite, biotite, and

Ca-rich plagioclase$_{An6-35}$ as compared to Ca-poor plagioclase$_{An0-20}$ from the central portions of pegmatite (Ackerman *et al.*, 2007). Allanite, hedenbergite, garnet, epidote, calcite, wollastonite, magnetite, chlorite, prehnite, apophyllite and pyrite occur in minor amounts in marginal parts of pegmatite dikes or as products of late hydrothermal processes and/or contamination (Vavřín, 1962; Žáček & Povondra, 1991; Novák & Hyršl, 1992; Žáček *et al.*, 2003).

Tourmaline-bearing pegmatites form rare dikes, 20 cm to 4 m thick, with homogeneous to simply zoned internal structure, cutting Fe-skarn and also biotite and pyroxene gneisses at the Vlastějovice region. They contain minor to accessory biotite, tourmaline, fluorapatite, whereas primary muscovite and garnet (except the spessartine dike) were found only in the pegmatite bodies hosted in gneisses. The pegmatites enclosed in Fe-skarn locally have very thin reaction rims, 1 mm to commonly 1–3 cm thick, with amphibole and less commonly also with biotite, garnet, fluorite and allanite. They are members of the granite-pegmatite system represented by ***footwall granite*** (Fig. 6.4) and several tourmaline-bearing pegmatite dikes (about 15 dikes were observed during the last 25 years). Granite body occurs along the footwall contact of the Fe-skarn body and underlying orthogneiss as a tectonically broken dike, about 200-250 m long and up to ~6 m thick in current outcrops (Fig. 6.5). It texturally evolves from medium- to coarse-grained and locally porphyric granite to coarse-grained granite with large blocks of K-feldspar, locally up to 30 cm in size. Accessory tourmaline is locally present. Footwall granite evidently generated several pegmatite dikes (Fig. 6-6.4) varying from texturally and mineralogically simple dikes (Kfs ≈ Qtz > Plg$_{An0-31}$) with rare tourmaline and locally amphibole, biotite and chlorite (**dikes No. 12 and 4**) to more evolved ***spessartine pegmatite***. It forms a zoned dike, up to 0.5 m thick and ~20 m long, mined out in 2008. It consists of dominant coarse-grained unit with locally developed graphic unit, blocks of K-feldspars, small quartz core and fine-grained albite locally with small masses of fluorite and several accessory minerals. The most evolved ***elbaite pegmatite***, which occurred in the western part of the Fe-skarn body and was very likely derived from footwall granite, was completely mined out in mid 1980s. This pegmatite dike, up to 2 m thick, exhibited simply zoned internal structure with fine- to medium-grained outer zone, coarse-grained inner zone with abundant graphic intergrowths (quartz + K-feldspar, quartz + tourmaline), blocky K-feldspar, albite and rare pockets with red elbaite, bavenite and datolite (Čech, 1985).

Very rare crosscutting dikes of amphibole-bearing and tourmaline-bearing pegmatites found recently confirmed that highly contaminated amphibole-bearing pegmatites crystallized earlier. Based on the detailed study of fluid inclusions and geological constraints (geothermal gradient, haplogranite solidus with 4.5 wt% B_2O_3, feldspars thermometry), Ackerman *et al.* (2007) suggested the following conditions for the amphibole-bearing and elbaite pegmatite formations: H_2O-CO_2 low salinity fluids (H_2O–CO_2 / N_2–H_3BO_3–NaCl fluids); P = 4.0–5.8 (3.1–4.3) kbar; T = 600–640 (500–570) °C (elbaite pegmatite in parentheses). The host rock temperature during elbaite pegmatite emplacement was estimated at ~300 °C. The P estimated for the elbaite pegmatite is slightly higher as compared to the complex pegmatites in the Moldanubian Zone, where presence of primary petalite and locally abundant andalusite suggests P < ~3.0 kbar (Novák, 2005).

3.6.4 Mineralogy

In order to demonstrate evident differences in contamination between amphibole-bearing pegmatites enclosed exclusively in Fe-skarn and tourmaline-bearing pegmatites cutting both Fe-skarn and gneisses, we focused on the chemical composition of the individual minerals (tourmaline and garnet) as well as overall mineral assemblages.

3.6.4.1 Amphibole-bearing pegmatites

Their mineral assemblages involve along with major oligoclase to andesine, quartz and locally K-feldspar and the following minor to major primary minerals – **amphibole > fluo-**

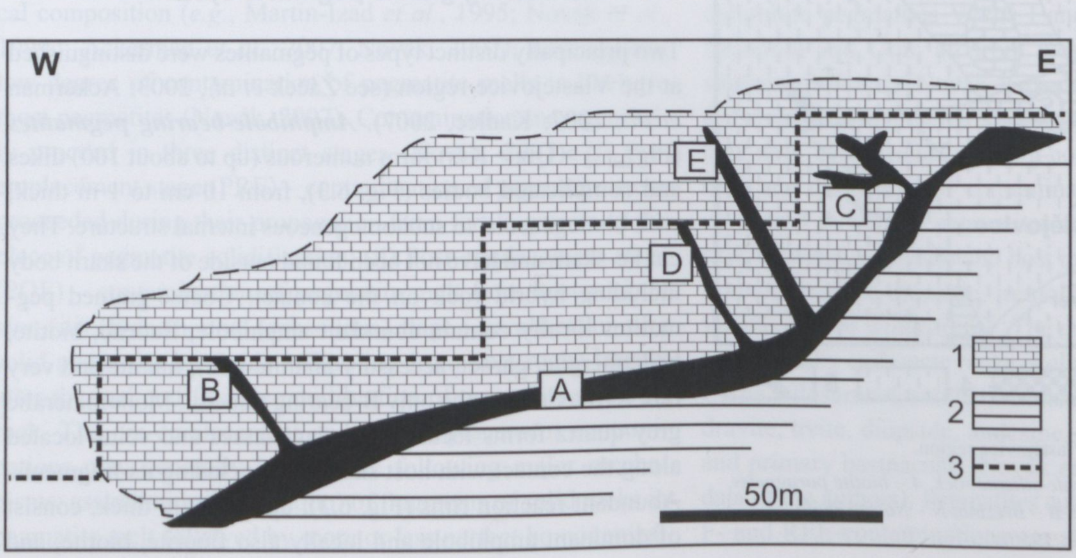


Fig. 6.4. Idealized section through the Fe-skarn with footwall granite and tourmaline-bearing pegmatites.
1 – Fe-skarn,
2 – orthogneiss,
3 – quarry floor levels,
A – footwall granite,
B – dike no.4,
C – dike no.12,
D – spessartine pegmatite,
E – elbaite pegmatite.

Fig. 6.5. Spessartine pegmatite derived from the footwall granite, cross-cutting the Fe-skarn body. Pegmatite dike thickness is ~50 cm.

rite > biotite > hedenbergite > andradite–grossular ≈ allanite ≈ epidote ≈ titanite ≈ calcite ≈ magnetite. Black to green-black amphibole as euhedral to subhedral phenocrysts, up to ~10 cm in size, and massive, coarse-grained aggregates, which belong to **hastingsite** (potassic to potassian) to **edenite** showing Fe^{3+} > ^{VI}Al (Fe^{3+} 0.70–1.07 apfu, ^{VI}Al = 0.18–0.30 apfu), high X_{Fe} (0.84–0.72), and highly variable ^{A}K (0.23–0.66 apfu) and ^{A}Na (0.22–0.41 apfu). Moderate F (0.69–0.72 wt%; 0.35–0.37 apfu) and 1.61–1.72 wt% H_2O (1.74–1.85 apfu OH; Žáček & Povondra, 1991) are typical. Subhedral to euhedral crystals of yellowish-brown **titanite**, ≤ 10 mm in size, occur in black hastingsite and fluorite chiefly from reaction zones between pegmatite and skarn. Titanite is Al-rich wt.% (7.81–9.75 wt% Al_2O_3, ≤ 0.31 apfu) and contains also elevated Fe ≤ 1.71 wt% of FeO = 0.05 apfu; 1.59 wt% F (0.16 apfu) and 0.74 wt% H_2O (0.16 apfu OH) (Vrána & Mrázek, 1985; unpubl. data of the authors). Abundant dark violet, purple to rare colourless **fluorite** forms coarse-grained aggregates, up to several dm in size, in pegmatite or in the exocontact zone. Fluorite locally predominates over quartz and feldspars. It is closely associated with allanite with deep violet to black rims around allanite grains. Ackerman (2005) presented REE-geochemistry and fluid inclusions study and suggested that fluorite crystallized under magmatic-hydrothermal transition conditions. Quite common **allanite-(Ce)**, present in amphibole-bearing pegmatites and host skarn, is often replaced by secondary fluorocarbonates (*e.g.*, **bastnaesite**).

3.6.4.2 Tourmaline-bearing pegmatites

Mineral assemblages of tourmaline-bearing pegmatites are very different from that of the amphibole-bearing pegmatites except for the presence of quartz, plagioclase, K-feldspar, and biotite. Also several very rare accessory minerals (fluorite, titanite, amphibole, allanite), occurring in minor to major amounts in amphibole-bearing pegmatites, are present in tourmaline-bearing pegmatites. Along with tourmaline and biotite, simple pegmatites contain accessory **fluorapatite**, **zircon**, **rutile**, **titanite**, **monazite-(Ce)**, **xenotime-(Y)**, **allanite-(Ce)**, **arsenopyrite** and **pyrite**, whereas **uraninite**, **cassiterite**, **niobian rutile**, **Sn-rich titanite**, a gadolinite–hingannite related mineral close to **minasgeraisite** and **Y-rich milarite** are known only from the spessartine pegmatite. Tourmaline (**schorl** to **elbaite**) is a typical minor mineral along with rare primary **danburite**, **annite** and accessory **magnetite**, **fluorite**, **zircon**, **pyrochlore-group minerals** and **manganocolumbite** in the elbaite pegmatite. Late **datolite** and **bavenite** were found in pockets associated with red elbaite, albite, K-feldspar and quartz. Tourmaline and garnet, accessory to minor minerals in pegmatites cutting Fe-skarn and associated gneisses, were selected to demonstrate the degree of contamination in tourmaline-bearing pegmatites.

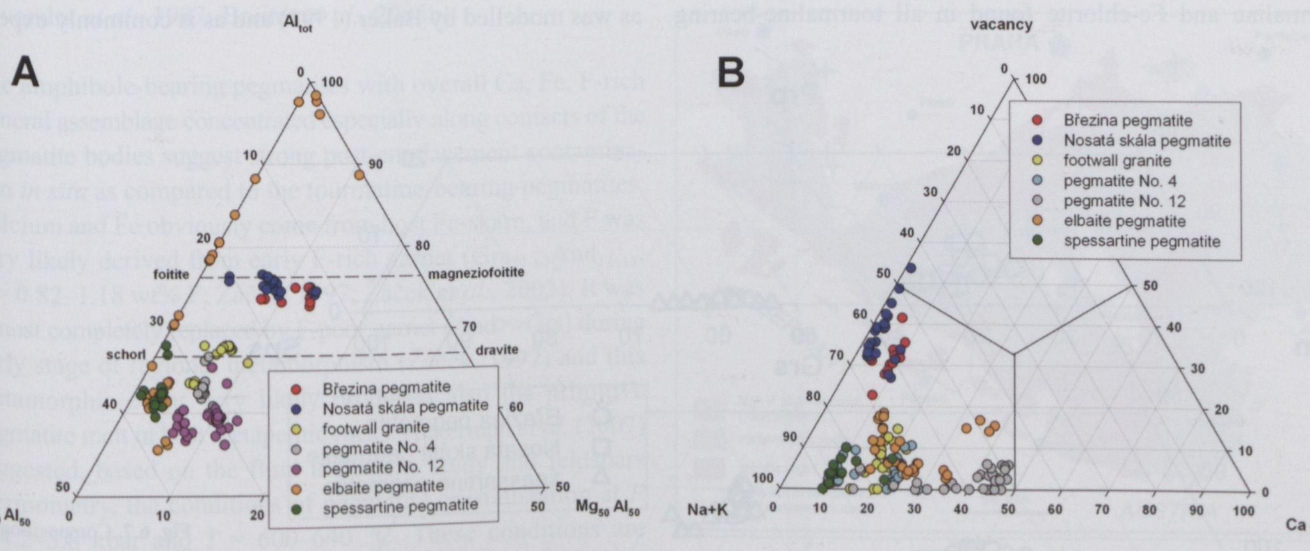


Fig. 6.6. Compositional diagrams of tourmaline from pegmatites of the Vlastějovice region.
A) Y + Z site occupancy (Al–Fe_{tot}–Mg); B) X-site occupancy (vacancy–Na–Ca).

Tourmaline

Tourmaline **(schorl)** from pegmatites in Fe-skarn is apparently Ca,Fe,F-enriched (0.15–0.48 apfu Ca, 2.56–2.70 apfu Fe^{2+}_{tot}, 0.22–0.47 apfu F; Fig. 6.6), whereas tourmaline **(schorl to dravite)** from pegmatites in gneisses yielded the composition 63-1.0.01–0.10 apfu Ca, 1.63–1.70 apfu Fe^{2+}_{tot}, 0.01–0.21 apfu F. The latter has evidently higher contents of Mg with Mg/(Fe + Mg) 0.219–0.521 as compared to that of tourmaline from footwall granite and two primitive pegmatites from Fe-skarn (dikes No. 12 and No. 4), with Mg/(Fe + Mg) 0.203–0.235 (Fig. 6.6), and especially to spessartine pegmatite with Mg/(Fe + Mg) 0.068–0.099 and the elbaite pegmatite with Mg/(Fe + Mg) 0.00–0.156. Also low concentrations of Mn are typical, and they increase, similarly as Fe, from pegmatites in gneiss (0.007–0.026 apfu) through footwall granite (0.023–0.036 apfu), pegmatites No. 4 and No. 12 (0.035–0.061 apfu) and spessartine pegmatite (0.108–0.130) to elbaite pegmatite with up to 0.929 apfu Mn in **elbaite.** High contents of Al (given as total Al in Y-site + Z-site + T-site) are typical for tourmaline from pegmatites from gneisses (6.469–7.040 apfu), whereas tourmaline from the other pegmatite dikes (except Li-enriched tourmaline from elbaite pegmatite) exhibits lower Al: footwall granite (6.012–6.290 apfu Al), pegmatite No. 4 (5.442–6.017 apfu), spessartine pegmatite (5.198–5.593 apfu) and pegmatite No. 12 (5.184–5.523 apfu) (Fig. 6.6). In the elbaite pegmatite extremely high variation in Al_{tot} = 4.806–8.289 apfu was found.

Tourmalines from pegmatites cutting gneisses suggest participation of the following dominant substitutions: $FeMg_{-1}$ and $\square OH\,(NaO)_{-1}$. However, tourmalines from other geochemically primitive pegmatites in the Moldanubicum show quite different exchange vectors (*cf.* Povondra, 1981; Novák *et al.*, 2004b). Tourmalines from pegmatites cutting Fe-skarn are evidently distinct in high contents of Ca and Fe and participation of the general substitutions: $CaR^{2+}\,(NaAl)_{-1}$, $R^{2+}OH\,(AlO)_{-1}$ is suggested. However, due to fine-grained intergrowths of tourmaline and Fe-chlorite found in all tourmaline-bearing pegmatites cutting Fe-skarn except for the elbaite pegmatite, determination of Fe^{2+}/Fe^{3+} by Mössbauer spectroscopy was not possible. Consequently, the above-elucidated substitutions are only approximate.

Garnet

Garnets from two pegmatites in gneisses (Březina, Nosatá skála) are quite homogeneous in the BSE images, but they are slightly heterogeneous, namely in Fe/Mn (Fig. 6.7). Garnet ($Alm_{72-63}Sps_{30-22}Prp_{8-4}Grs_{2-1}$) from the pegmatite Březina exhibits slightly decreased Mg and Ca and increased Fe along rims. Garnet ($Alm_{67-62}Sps_{35-30}Prp_{3-2}Grs_{1-0}$) from Nosatá skála is homogeneous. Garnet ($Alm_{43-35}Sps_{61-51}Prp_{1-0}Grs_{9-3}And_{2-0}$) from the spessartine pegmatite is evidently enriched in Y (0.62 wt% Y_2O_3, 0.033 apfu), whereas Sc and F are below the detection limits. The LA-ICP-MS study confirmed elevated contents of HREE (Ho, Er, Tm, Yb) and Sr in garnet from spessartine pegmatite up to 2 orders higher as compared to the pegmatites (Březina, Nosatá skála) from gneisses. Concentrations of other trace elements including LREE, are very similar.

3.6.5 Concluding remarks

Granite and pegmatite bodies closely related to Fe-skarn (footwall granite, pegmatite No. 12, pegmatite No. 4, spessartine pegmatite, elbaite pegmatite) (Fig. 6.4) represent a unique example of granite-pegmatite system, where individual small pegmatite dikes show unambiguous relationship to well-defined parts of the texturally heterogeneous parental granite body with the exception of the elbaite pegmatite mined out in about 1985. Both pegmatites from gneisses (Březina and Nosatá skála) are very likely related to the same magmatic event as granite-pegmatite system cutting Fe-skarn. Such a parental granite, however, is very small as compared to the size of potential granitic plutons fertile to granitic pegmatites as was modelled by Baker (1998) and as is commonly expect-

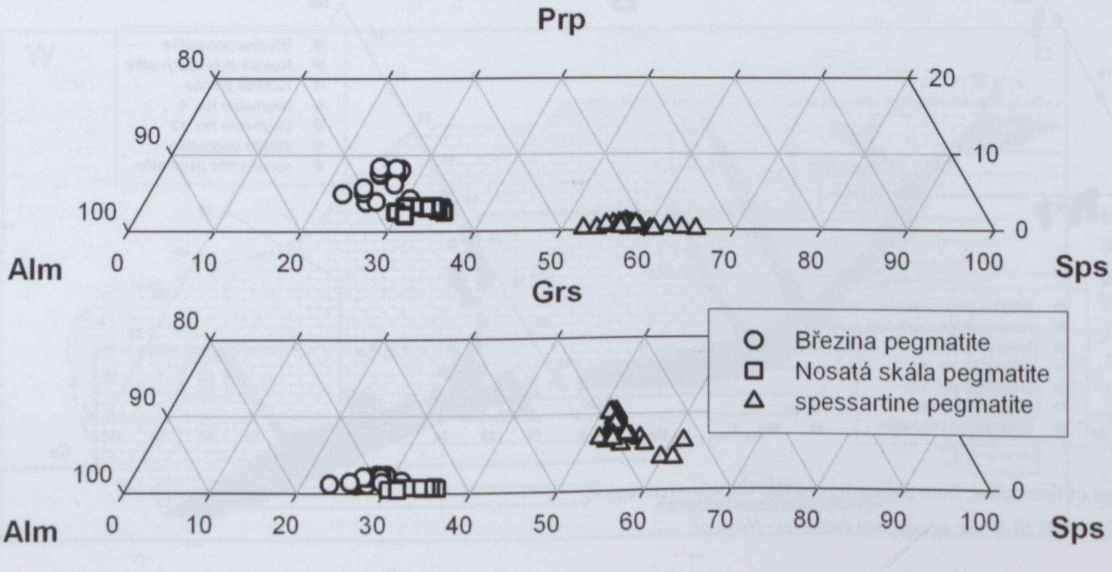


Fig. 6.7. Compositional diagrams of garnet from pegmatites of the Vlastějovice region.

ed (Černý, 1991a; Černý, 1991b; London 2008). Hence, the granite-pegmatite system in Vlastějovice is very unusual and raises the question how granites fertile to granitic pegmatites appear including their size, textures, compositions etc. (see Martin & De Vito, 2005).

Tourmaline (schorl) from pegmatites cutting Fe-skarn is apparently Ca,Fe,F-enriched, as compared to tourmaline (schorl to dravite) from pegmatites enclosed in gneisses. Their composition is comparable to that of tourmaline from other primitive pegmatites in the Moldanubian Zone (Novák *et al.*, 2004b). The chemical composition of tourmaline suggests moderate *in situ* contamination of pegmatites cutting Fe-skarn, which is evidently higher in less fractionated and differentiated pegmatite bodies (dike No. 12) relatively the more evolved to the spessartine pegmatite and chiefly to elbaite pegmatite. High degree of fractionation is indicated also by elevated Li, Mn and F concentrations. Garnet from the spessartine pegmatite is evidently Ca-,Mn-,Fe^{3+}-enriched as compared to garnets from pegmatites enclosed in gneisses, hence, both higher degree of fractionation and Ca,Fe-contamination are evident in this pegmatite. Elevated Y and REE contents as compared to garnet from the pegmatites in gneisses support also introduction of Y and REE from Fe-skarn (with common accessory allanite). Contamination demonstrated by chemical composition of minerals and mineral assemblages is evident in pegmatites cutting Fe-skarn including elbaite pegmatite. It is in contrast with fluid inclusion study (see Ackerman *et al.*, 2007), where no contamination was indicated in evolution of fluid inclusions from the elbaite pegmatite as compared to amphibole-bearing (barren) pegmatites.

Both tourmaline and garnet from the pegmatites cutting Fe-skarn are evidently Ca- and Fe-enriched (Fig. 6.6, Fig. 6.7), whereas chemical composition of tourmaline and garnet from pegmatites cutting gneisses is very similar to those from primitive pegmatites in the Moldanubicum, (tourmaline – see *e.g.*, Povondra, 1981; Novák *et al.*, 2004b; garnet – see *e.g.* Povondra *et al.*, 1987; Breiter *et al.*, 2005b).

The amphibole-bearing pegmatites with overall Ca, Fe, F-rich mineral assemblage concentrated especially along contacts of the pegmatite bodies suggest strong post-emplacement contamination *in situ* as compared to the tourmaline-bearing pegmatites. Calcium and Fe obviously come from host Fe-skarn, and F was very likely derived from early F-rich garnet ($Grs_{79-87}And_{12-18}$; F = 0.82–1.18 wt% F; Žáček, 1997; Žáček *et al.*, 2003). It was almost completely replaced by F-poor garnet (And>>Grs) during early stage of regional metamorphism (Žáček, 1997) and this metamorphic event very likely produced also the primitive pegmatite melt in host metapelitic rocks. Ackerman *et al.* (2007) suggested, based on the fluid inclusions study and feldspars thermometry, the conditions of pegmatite crystallization at P = 4.2–5.8 kbar and T = 600–640 °C. These conditions are slightly lower than the conditions of regional metamorphism at P = 4.5–6.5 kbar and T = 590–680 °C estimated by Žáček, 1997).

3.7 Field stop 7: Myšenec near Protivín, Písek region – Tourmaline-beryl pegmatite with late Mg-rich alteration

(Milan Novák & Radek Škoda)

3.7.1 Introduction to the beryl pegmatites in the Moldanubian Zone

Beryl-bearing pegmatites with abundant tourmaline are common in the Moldanubian Zone (Fig. 7.1). Three distinct paragenetic types (all beryl-columbite subtype in the sense of Černý & Ercit, 2005) were distinguished. (i) Beryl pegmatites with common primary muscovite, accessory garnet (spessartine–almandine), apatite and columbite + cassiterite, as typical Nb-Ta-Ti-Sn oxide minerals, are randomly distributed in the Moldanubian Zone. They mostly form small bodies within the individual pegmatite districts, where complex (Li) pegmatites commonly prevail. (ii) Beryl pegmatites with rare primary muscovite, minor to accessory cordierite, apatite and niobian (tantalian) rutile and ilmenite as typical Nb-Ta-Ti oxide minerals are concentrated in two isolated regions. They contain quite a high number of accessory minerals as compared to the first type including common REE-minerals (*e.g.*, monazite-(Ce), xenotime-(Y), *písekite* – metamict mineral close to samarskite, see details below). Localities Věžná I and II, western Moravia (Černý & Novák, 1992) and chiefly localities in the Písek region, southern Bohemia represent typical occurrences of the latter pegmatite type. (iii) Beryl pegmatites with primary Be-bearing phosphates (hurlbutite) and closely related to granites of the Central Moldanubian Pluton (Novák, 1995; Cempírek et. al., 1999; Pavlíček *et al.*, 2009) are very rare.

Pegmatites from the Písek region (*e.g.*, Písek – Obrázek 1, 2, 3, Nový rybník; Údraž; Horní Novosedly; Havírky, Myšenec; (Fig. 7.2) cut migmatized gneisses and amphibole-biotite syenites of the Mehelník Massiv. Small dike-like bod-

Fig. 7.1. Schematic geological map of the Moldanubian Zone with major occurrences of beryl pegmatites.

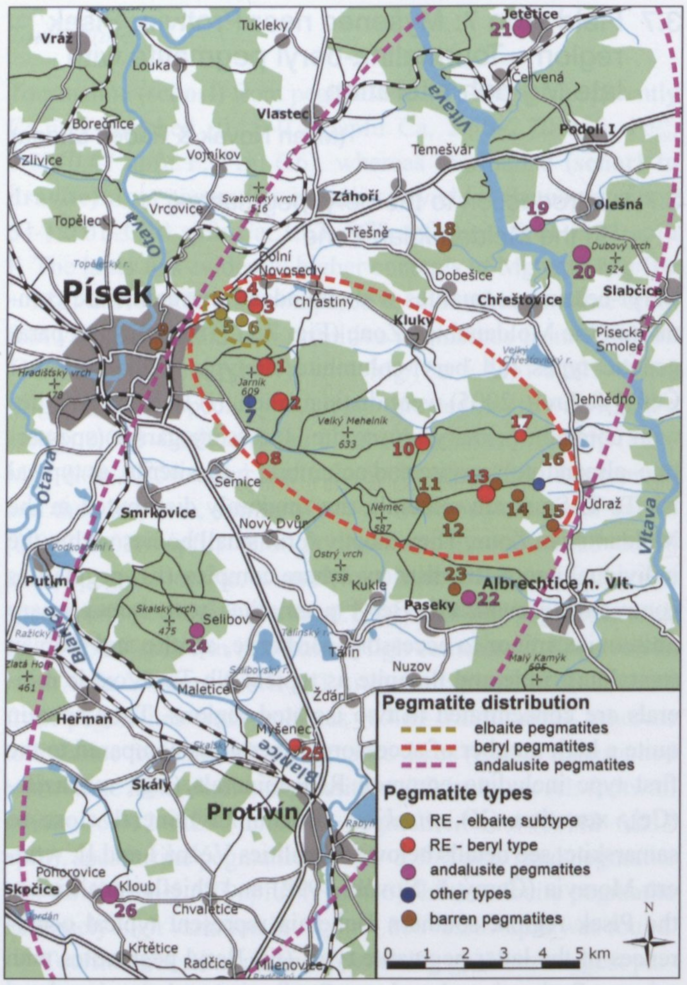


Fig. 7.2. Schematic map of the Písek pegmatite district with marked position of rare-element (RE-) and primitive pegmatites (after Novák & Cícha, 2009).

ies of leucocratic granites with abundant nodules of tourmaline + quartz are common in this region and they may be fertile granites of the Písek pegmatites. Granitic pegmatites vary from less evolved and commonly small dikes with common tourmaline and locally rare beryl to mostly large, highly differentiated and more fractionated pegmatite dikes, up to 25 m thick, with common tourmaline and beryl, and numerous accessory minerals (apatite, niobian rutile, ilmenite, ixiolite, columbite–tantalite, monazite-(Ce), xenotime-(Y), zircon, písekite). Zoned pegmatites typically show complicated internal structure with a border granitic unit (K-feldspar + quartz + albite-oligoclase + biotite), graphic unit (K-feldspar + quartz ± biotite), blocky K-feldspar and a large quartz core, locally developed as rose quartz. In highly evolved dikes common albite unit (albite + quartz ± tourmaline, muscovite) is developed between the quartz core and the blocky K-feldspar unit and contains most accessory minerals. The latest unit is represented by a fine-grained aplitic unit cutting all textural-paragenetic units in thin veins (1–5 cm thick) (Čech, 1985).

Along with beryl, as the most abundant primary Be-bearing mineral, rather rare primary danalite was also found at two localities. Beryl occurs in several paragenetic, morphological and compositional types. Common, yellowish to greenish beryl in more or less perfectly developed columnar crystals, up to 25 cm long, is enclosed in K-feldspar, albite and/or massive quartz. Rare elongated and corroded grains of golden yellow heliodor (Fig. 7.3), pale blue aquamarine, up to 3 cm in size, and very rare pink morganite are related to the albite unit or the quartz core (Sejkora *et al.*,1998). Beryl is locally altered, and open vugs after dissolved beryl crystals are lined with tabular crystals of bertrandite (Fig. 7.3), typically associated with yellow muscovite. Rare phenakite and milarite, as likely products of beryl alteration, were also found at some localities. Dark brown aggregates of danalite, up to 2 cm in size, contains thin zoned veinlets consisting of a narrow zone of helvite adjacent to danalite and small grains of quartz, schorl, phenakite and bertrandite (?). Niobian rutile as a typical accessory mineral in subhedral crystals, up to 3 cm long, is highly heterogeneous in composition with microscopic exsolutions of Ti,W-rich ixiolite enclosed in depleted niobian rutile (Černý *et al.*, 2007). Písekite described from the Písek pegmatites (Krejčí, 1923) as needles, up to 4 cm long, is a highly metamict mineral related to the samarskite group (Bouška & Johan, 1972), closely associated with monazite, and xenotime. New data of the authors show that primary precursor (*písekite*) is compositionally more complicated mineral and the analyses are close to samarskite, euxenite, and/or fergusonite compositions, respectively. Needle-like aggregates are composed of rare hydrated relics of the above minerals and complex mixture of several secondary phases, which are compositionally close to REE,U-rich pyrochlore, scheelite, ixiolite, columbite, zircon, xenotime, rutile, zirconolite and galenite. Along with the beryl pegmatites, simple peraluminous pegmatites with abundant andalusite, tourmaline, and accessory corundum also occur in this region (Fig. 7.2).

Myšenec pegmatite represents a moderately evolved beryl pegmatite located in the southernmost margin of the Písek pegmatite region (Fig. 7.2). This locality is famous chiefly due

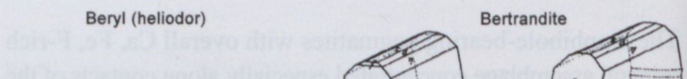


Fig. 7.3. Crystals of selected minerals from Písek pegmatites (Vrba, 1888).

to large aggregates of black tourmaline exposed at the outcrop in the center of Myšenec village. This outcrop has been protected as natural reserve since 1986.

3.7.2 General geology and internal structure

The pegmatite dike cuts amphibole-biotite syenite (Fig. 7.4). Host small body of syenite is a typical member of the rock complex of Gföhl Unit involving migmatized gneisses, biotite orthogneiss, leucocratic granulites, rare eclogites and dikes of leucocratic granites typically with nodules of tourmaline + quartz also exposed in several outcrops in the village. The zoned pegmatite is approximately 3 m thick and several tens m long and has sharp contact with host syenite (Novák *et al.*, 1997b).

In the current outcrop, the almost symmetrically zoned internal structure of pegmatite consists of the following textural-paragenetic units similar to those in other granitic pegmatites of the Písek region (Fig. 7.2): (i) a border graphic unit (K-feldspar + quartz + albite + biotite ± tourmaline); (ii) a blocky core-margin unit with K-feldspar crystals, up to 20 cm in diameter; (iii) a quartz core locally as pale pink rose quartz; (iv) rare aggregates of medium-grained albite, commonly developed along the contact of the quartz core and the blocky unit with rare beryl. Primary muscovite is absent and rare late muscovite occurs in blocky K-feldspar. Giant tourmaline aggregates, radiating fans of prismatic tourmaline crystals, up to 80 cm long, are a dominant feature of the outcrop (Fig. 7.5). A specimen of beryl examined was found at an occasional exposure located ~20 m from the tourmaline-aggregate outcrop.

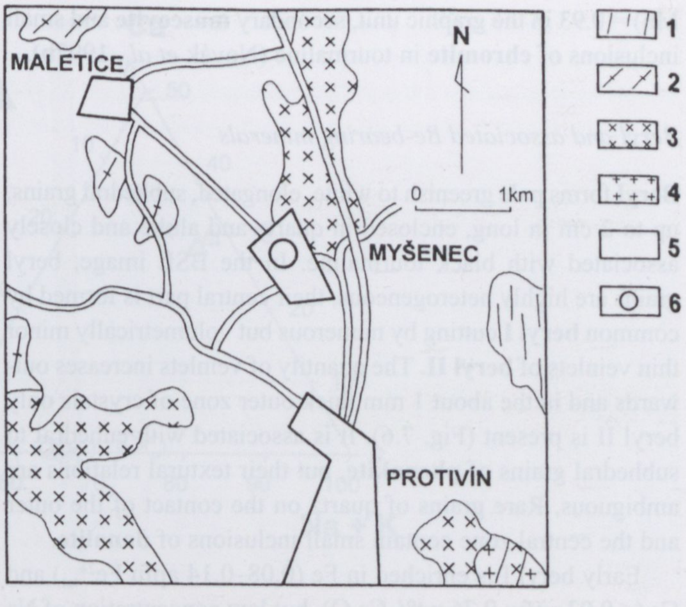


Fig. 7.4. Geological sketch of the Myšenec area.
1 – migmatite, 2 – biotite and two-mica orthogneiss, 3 – syenite (durbachite), 4 – leucocratic granite, in part tourmaline-bearing, 5 – Quaternary cover, 6 – locality (Novák et al., 1997b).

3.7.3 Mineralogy

Tourmaline, beryl and closely associated Be-bearing minerals (phenakite, danalite) are the only minerals attractive enough to be described in detail from this locality. Other minerals found in the pegmatite include **biotite**, rare **ilmenite** with Fe/(Fe +

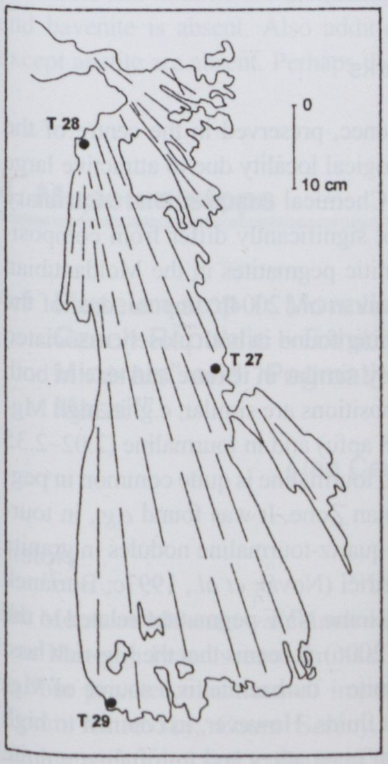


Fig. 7.5. Giant aggregate of tourmaline in pegmatite and sketch of the rightmost one (after Novák *et al.*, 1997b; photo: J. Cícha).

Mn) = 0.93 in the graphic unit, secondary **muscovite** and small inclusions of **chromite** in tourmaline (Novák *et al.*, 1997b).

Beryl and associated Be-bearing minerals

Beryl forms pale greenish to white, elongated, subhedral grains, up to 2 cm in long, enclosed in quartz and albite and closely associated with black tourmaline. In the BSE image, beryl grains are highly heterogeneous, their central part is formed by common **beryl I** cutting by numerous but volumetrically minor thin veinlets of **beryl II.** The quantity of veinlets increases outwards and in the about 1 mm thick outer zone of crystals only beryl II is present (Fig. 7.6). It is associated with euhedral to subhedral grains of **phenakite**, but their textural relations are ambiguous. Rare grains of quartz on the contact of the outer and the central zone contain small inclusions of **danalite**.

Early beryl I is enriched in Fe (0.08–0.14 apfu Fe^{2+}_{tot}) and Cs (≤ 0.03 apfu; 0.76 wt% Cs_2O), but low concentration of Na (0.05–0.07 apfu) is typical. It differs from ordinary beryl of the Písek pegmatites by higher Fe and Cs. Late beryl II is Na- and Mg-enriched (0.14–0.21 apfu; 0.12–0.18 apfu, respectively), but Fe-poor (≤ 0.06 apfu Fe^{2+}_{tot}) and with Cs below detection limit. Danalite $Dn_{61-56}Hv_{34-39}Gh_{4-5}$ is Zn-enriched (0.30–0.38 apfu) as compared to danalite-helvite from Horní Novosedly (Fig. 7.7).

Tourmaline

Three distinct morphological and paragenetic types of tourmaline were found in this pegmatite. The first one is represented by medium-grained aggregates closely associated and/or locally replacing biotite in outer unit. The second one is the giant tourmaline aggregates, radiating from the upper part of core-margin towards the center of the dike. This aggregate is fractured and healed by quartz. The last type is represented by subhedral columnar crystals, up to 3 cm long, and coarse-grained aggregates closely associated with beryl and occurring within the albite unit or on its contact with massive quartz. In the BSE image, the last type of tourmaline is cut by numerous thin veinlets of dravitic composition.

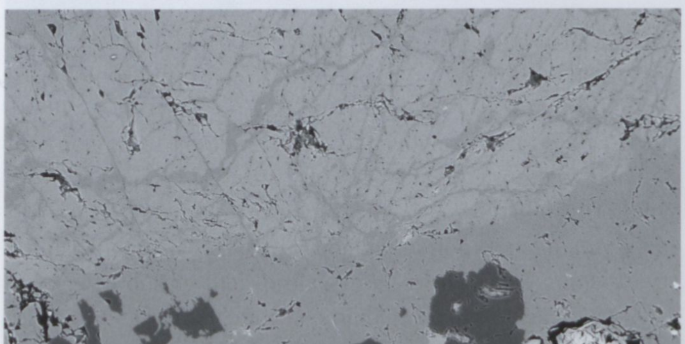


Fig. 7.6. BSE image of a beryl + phenakite + danalite assemblage. Beryl I (light grey) with veining and rim of beryl II (grey), replaced by phenakite (dark grey).

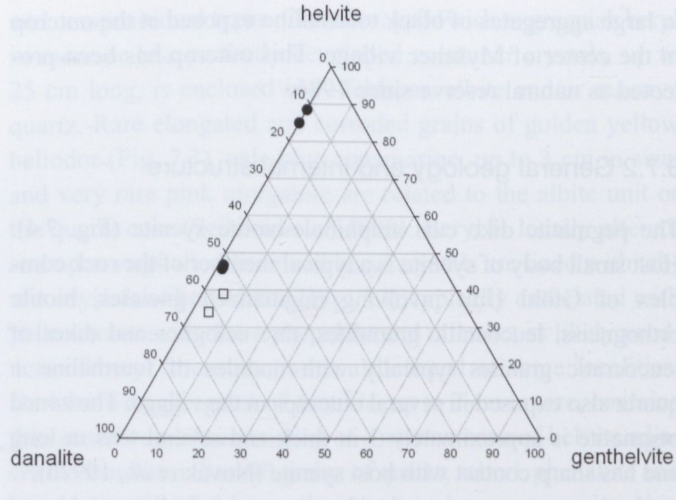


Fig. 7.7. Composition of danalite–helvite in pegmatites from the Písek region. *Open squares – Myšenec, full circles – Dolní Novosedly.*

Chemical compositions of the individual primary tourmaline paragenetic types vary from **schorl–dravite** in the outer unit (1.0–1.4 apfu Mg) and in early part of large aggregate (Fig. 7.8) to Mg-poor **schorl** (~0.2–0.3 apfu Mg) in terminal parts of large aggregate and in tourmaline associated with beryl. All types of primary tourmaline are Al-rich (6.49–6.62 apfu) and Ca-poor (≤ 0.01 apfu). Secondary **dravite** (2.1–2.4 apfu Mg) in late veinlets is Ca-rich (up to 0.35 apfu) and Al-poor (5.5–5.7 apfu; see Fig. 7.8).

3.7.4. Concluding remarks

Beryl pegmatite from Myšenec, preserved in the centre of the village, is a unique mineralogical locality due to attractive large aggregate of tourmalines. Chemical compositions of primary beryl and tourmaline do not significantly differ from compositions found in relevant granitic pegmatites in the Moldanubian Zone (Povondra, 1981; Novák *et al.*, 2004b; unpubl. data of the authors). However, late veining found in both closely associated minerals is unusual. It is very similar in texture and size in both minerals, and also the compositions are similar, e.g. in high Mg-contents in beryl (0.12–0.18 apfu) and in tourmaline (2.02–2.35 apfu). Similar late veining in tourmaline is quite common in pegmatites from the Moldanubian Zone. It was found *e.g.*, in tourmaline from pegmatite and quartz-tourmaline nodules in granite at Lavičky, near Velké Meziříčí (Novák *et al.*, 1997c; Buriánek & Novák, 2004) and also in some NYF pegmatites related to the Třebíč pluton (Škoda *et al.*, 2006). It seems that the Mg-rich host rock, amphibole-biotite syenite – durbachite, is a source of Mg- and potentially also Ca-rich fluids. However, in contrast to high activity of Ca in fluids from pegmatites and tourmaline granite closely associated with the Třebíč pluton, which is manifested by

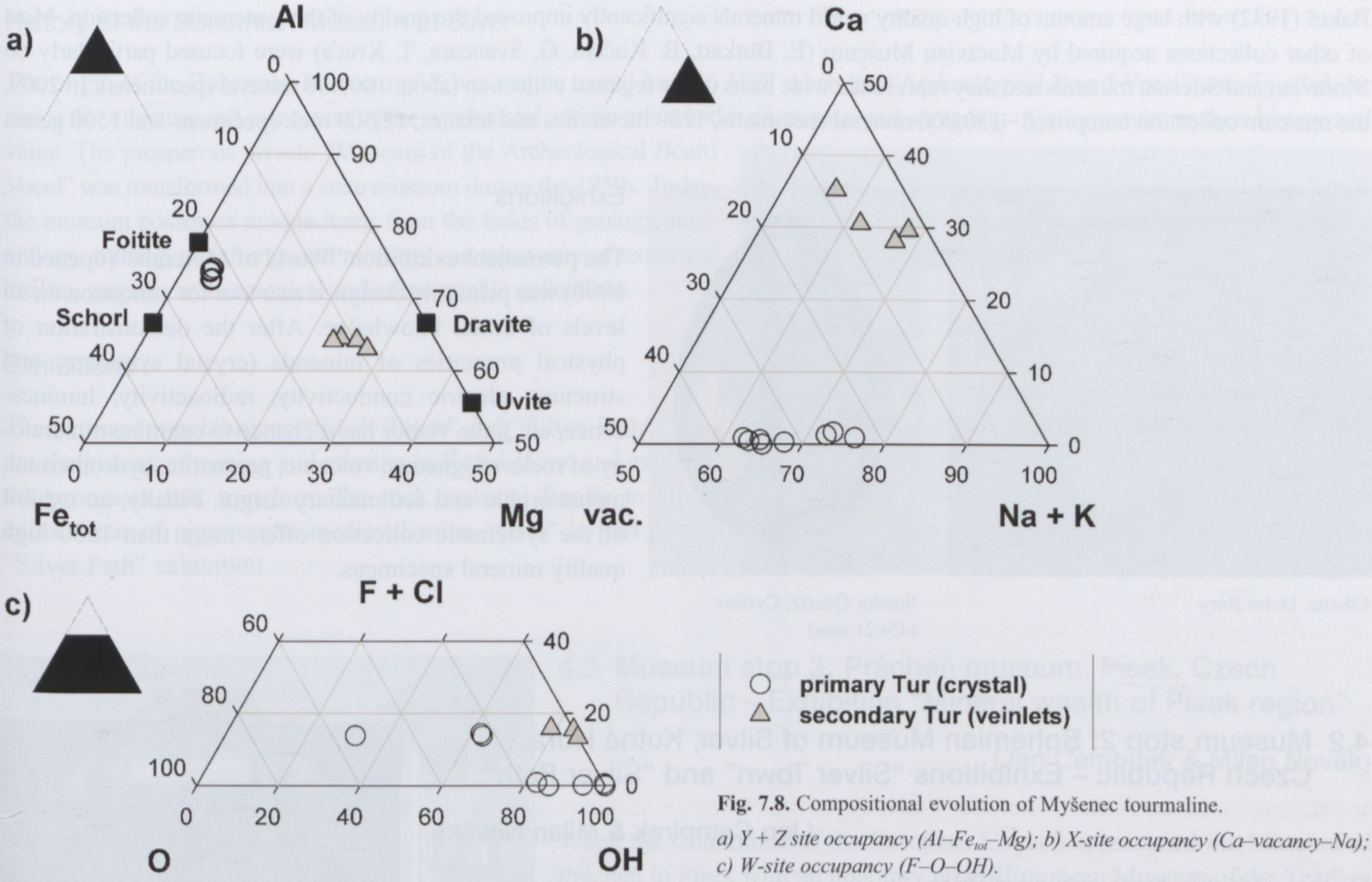


Fig. 7.8. Compositional evolution of Myšenec tourmaline.

a) Y + Z site occupancy (Al–Fe$_{tot}$–Mg); b) X-site occupancy (Ca–vacancy–Na); c) W-site occupancy (F–O–OH).

abundant bavenite after beryl and additional secondary phases rich in Ca (titanite, pyrochlore, epidote; Škoda *et al.*, 2006), in pegmatites of the Písek region common bertrandite and rare phenakite and milarite are dominant alteration product of beryl and bavenite is absent. Also additional late Ca-rich minerals except apatite are absent. Perhaps the high activity of P in pegmatite and consequent crystallization of abundant apatite in the Písek pegmatites comparing to P-poor Třebíč pegmatites (apatite is very rare) enabled to extract Ca from the system and prevented the formation of other Ca-rich late phases like bavenite, secondary titanite II and pyrochlore (Škoda *et al.*, 2006; Škoda & Novák, 2007).

4. Museum stops

4.1 Museum stop 1: Moravian Museum, Brno, Czech Republic – Exhibitions "World of Minerals" and "Pegmatites of the Bohemian Massif"

(Jan Cempírek & Milan Novák)

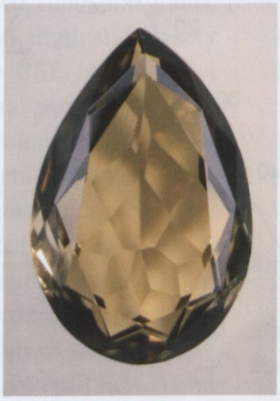
MORAVSKÉ ZEMSKÉ MUZEUM

History

The Moravian Museum was founded in 1817 by Emperor Francis I, as Museum Francisceum Brunae. The collection was based on four private collections of important Moravian noblemen (Count Mitrovsky, Count Serény, Count Salm and Prince Liechtenstein) donated to the museum in 1818. The collection of Ing. F. Kretschmer (1906) and particularly that of Dr. J.

Bakeš (1932) with large amount of high-quality world minerals significantly improved the quality of the systematic collection. Most of other collections acquired by Moravian Museum (E. Burkart, B. Kučera, G. Švancara, T. Kruťa) were focused particularly on Moravian and Silesian minerals and they represent a wide basis of the regional collection (about 100,000 mineral specimens). In 2009, the museum collection comprised ~130,000 mineral specimens, 1200 meteorites and tektites, 12,500 rock specimens and 1500 gems.

Elbaite, Dolní Bory



Smoky Quartz, Cyrilov (45×21 mm)

Exhibitions

The permanent exhibition "World of Minerals" (opened in 1990) was primarily designed as a tool for education on all levels of initial knowledge. After the demonstration of physical properties of minerals (crystal symmetry and structure, electric conductivity, radioactivity, luminescence, etc.), the visitor has a chance to examine mineralogy of rocks of igneous, volcanic, pegmatite, hydrothermal, metamorphic and sedimentary origin. Finally, an exhibit of the systematic collection offers more than 1500 high quality mineral specimens.

4.2 Museum stop 2: Bohemian Museum of Silver, Kutná Hora, Czech Republic – Exhibitions "Silver Town" and "Silver Path"

(Jan Cempírek & Milan Novák)

History of Kutná Hora mining district

The history of Kutná Hora was always interlocked with silver mining industry. First written records about silver in Kutná Hora come from 1260. Soon after, in 1290, an extensive "silver rush" caused a chaotic growth of the mining settlement for tens of thousands miners. In that time, the Kutná Hora district was generating about 1/3 of the silver production in whole Europe.

Front page of the "Kuttenberger Graduale" (about 1490)

In 1300, King Wenceslaus II invited Italian lawyer Gozzius of Orvieto who created a new modern mining code and minting reform – *Ius Regale Montanorum* (or *Constitutiones iuris metallici*) – which was later used for several centuries in many European countries (in the Czech Kingdom, the law was fully valid till 1834). The minting reform replaced the contemporary currency by new uniform silver coins – the "*Prague groschen*".

After gradual decline in the 14th century and the Hussite wars (15th century), the mining was renewed on new deposits in the vicinity of Kutná Hora and the town flourished for almost 150 years. Later, the mines faced problems with water pumping form great depths and therefore the silver mining slowly declined in the 16th century. Intensive silver import from America and the Thirty Years' War finally stopped the mining activities.

The last era of mining started in the 1940s when attention focused on lead and zinc. The production successfully continued till 1991 when the last mine was closed.

History of the Bohemian Museum of Silver

The origin of the Bohemian Museum of Silver can be traced back to 1877 when the "Archeological Board Vocel" was founded. Its aim was collecting and protection of the written and artistic relics and monuments, and spreading of information on their history and value. The prosperous private "Museum of the Archeological Board Vocel" was transformed into a state museum during the 1950s. Today, the museum possesses unique items from the fields of geology, mineralogy, mining, metallurgy and minting, and takes care of extensive artistic, graphic, archaeological and ethnographic collections.

Exhibitions

The permanent exhibitions "Silver Town" and "Silver Path" present the history of mining and minting in Kutná Hora, and explains the processes that transform the rock material finally to silver coins. Visit of pictoresque medieval mine "Osel" is part of the "Silver Path" exhibition.

4.3 Museum stop 3: Prácheň museum, Písek, Czech Republic – Exhibition "Mineral wealth of Písek region"

(Jan Cempírek & Milan Novák)

When the Committee of the European Council appreciated the Museum of Prácheň in Písek with an honorary prize "European Museum of the Year" in 1996, the absolute majority of Czech and foreign visitors stated that it was fully legitimate. Perfectly arranged expositions in modern design provide plastic illustrations of the Písek region. The visitors can find there many topics such as Prehistory and Slavic Age, Beginnings of the castle and the city of Písek, History of the region, Protected areas, Mineral resources, Cultural traditions of the Písek region, Gold in the Otava basin, Fishes and fishery.

Mineral collection

The Prácheň museum mineral collection provides valuable documentation of the Písek region, which is especially rich in pegmatites (mostly NYF-family). Their typical minerals comprise beryl, tourmaline, monazite, xenotime, písekite and other U-Th-REE phases. Besides pegmatites, the collection presents especially exquisite samples of gold from quartz veins, various secondary phosphates, or tektites from South Bohemian occurrences.

Písekite, Písek

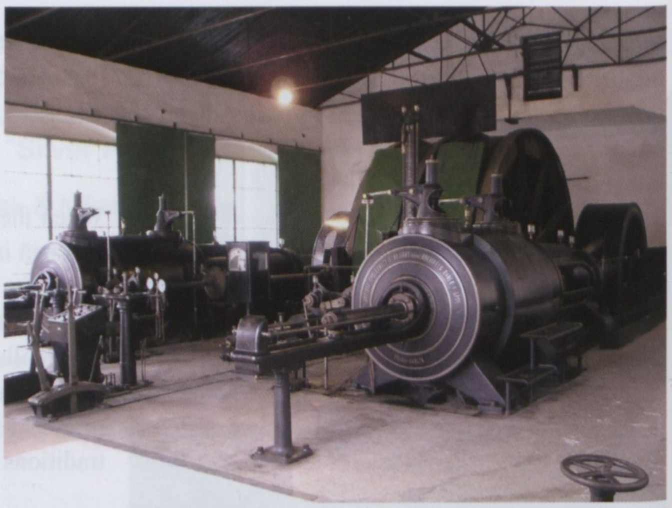
Heliodor, Písek

4.4 Museum stop 4: Mining museum in Příbram, Czech Republic (a Pb-Zn-Au-Ag ore district) – Main topics: mining history of the Příbram district, base metals, uranium

(Vojtěch Janoušek, Czech Geological Survey, Prague, Klárov 3, 118 21 Praha 1, Czech Republic; vojtech.janousek@geology.cz)

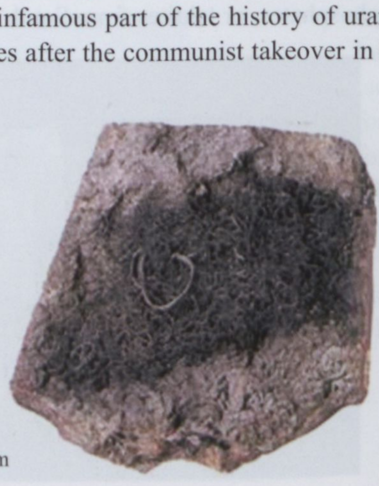
The mining museum is situated in the area of the historical Ševčin shaft, built in 1813 on the site of a medieval mining pit dating back to the 16th century. The original mining area of the Vojtěch pit, which was founded in 1779 (and which was a place of world's primacy in reaching the vertical depth of 1 000 m in 1875), as well as the Anna pit, which was driven in 1789 also belong to the museum.

The exhibition portrays the history of exploitation of the historical silver district and the extraction of the uranium deposit after 1948. The most valuable exhibits include the oldest documents concerned with the beginning of the mining activity, bronze objects from the period of the Celtic colonization, then the oldest written document confirming the existence of Příbram (from 1216), and the first written document concerned with the local smelting works and mines (from 1311).

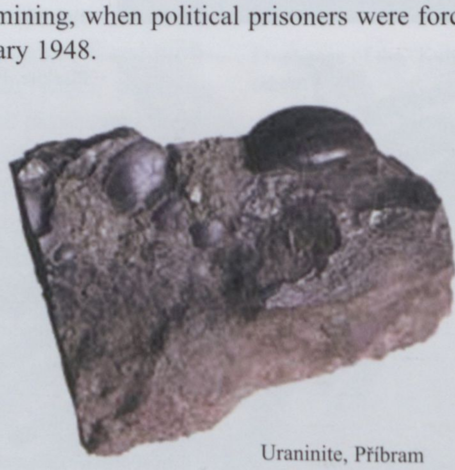


The mining, measuring and rescue equipment is also on exhibit close to the Ševčin shaft. Its pit-head gear, dating from 1879, was built in the style of industrial architecture of the 19th century and there is a proposal pending for it to be included on the UNESCO World Heritage list. A technical monument – a steam winding engine of the Anna shaft from 1914 – is one of the highlights of the Mining Museum. In the engine room of the Vojtěch shaft there is another unique steam winding engine from 1889. From the yard of the Anna shaft it is possible to go underground by a little mining train to the 260 m long Prokop Gallery from 1832, which leads to the mouth of the Prokop pit, which is the deepest shaft of the Březové Hory mining district (with the depth of 1600 m).

Furthermore, the exhibitions include unique mineralogical and geological samples from the Březové Hory silver mining district, as well as from uranium deposits in the Příbram region. The collection of silver minerals dominates the exhibition. The museum also recalls the infamous part of the history of uranium mining, when political prisoners were forced inhumanely to work in the uranium mines after the communist takeover in February 1948.



Native silver, Příbram



Uraninite, Příbram

4.5 Museum stop 5: National Museum, Praha, Czech Republic – Permanent exhibition of minerals

(Jan Cempírek & Milan Novák)

History

The National Museum was founded in 1818. The first donations to its mineralogical collection were provided by Count Kaspar Maria von Sternberg and other Czech noblemen; the first courator of the collection was Prof. F.X.M. Zippe (1821–1849). The collection was enriched by numerous donations and in 1893 the Department of Mineralogy and Petrology was established. In the same year, large permanent exhibition of minerals was opened in the museum building at the top of Václavské náměstí.

MUSAEUM NATIONALE 1818

NÁRODNÍ MUZEUM

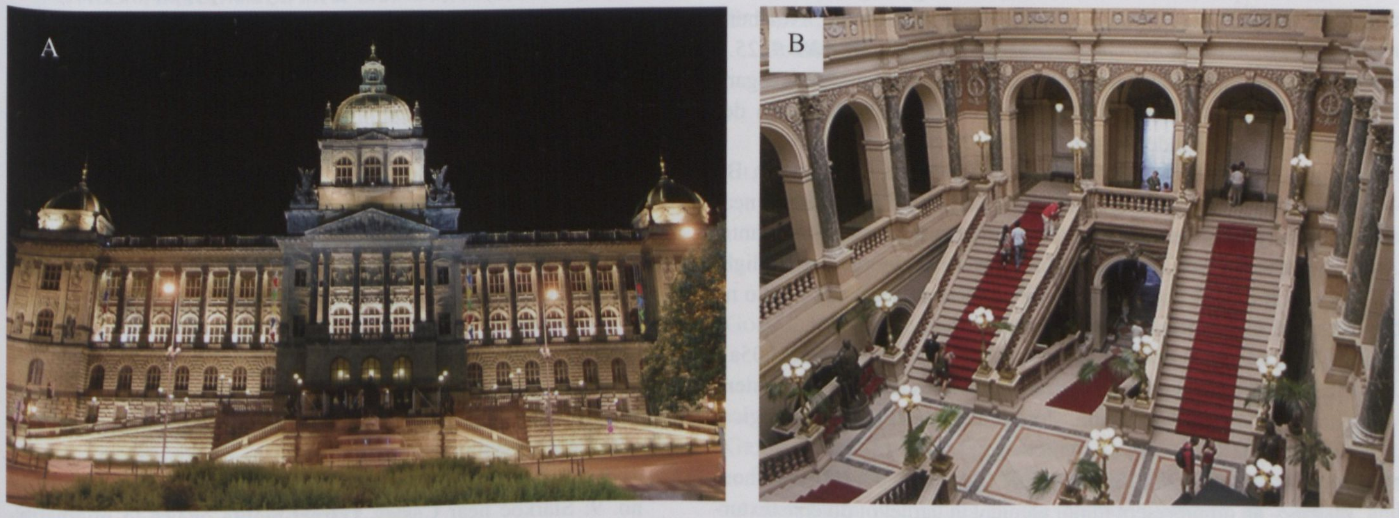
Mineralogical collection

The collection contains ~130,000 mineral specimens, 500 meteorites, 13,000 tektites, 23,000 rock specimens and 20,000 gems. Besides the systematic mineral collection from world and Czech localities, the museum also posseses rich collection of samples from various Czech ore deposits (especially Příbram, Jáchymov, etc.).

Count Kašpar Maria Sternberg, the founder of the National Museum

Exhibition

The permanent exhibition was originally arranged in 1893 in three large halls. The opening part of the exhibition presents a systematic collection of about 5000 specimens, which are currently arranged on the basis of Strunz's mineralogical system. Two other large halls are devoted to the ore mineral collections from Bohemian ore districts including the well-known classical localities Jáchymov and Příbram and other mineralogically significant deposits from different geological environments. Two smaller halls display gemstones, meteorites and tectites. The style of the main part of the exhibition has been maintained unchanged since 1893.



a) The main building of the National Museum in Prague.
b) Staircase in the atrium of the National Museum.

5. References

Ackerman, L. (2005): Magmatic vs. hydrothermal origin of fluorites from Vlastějovice, Bohemian Massif. Journal of the Czech Geological Society, **50**: 35–41.

Ackerman, L., Zachariáš, J. & Pudilová, M. (2007): P–T and fluid evolution of barren and lithium pegmatites from Vlastějovice, Bohemian Massif, Czech Republic. International Journal of Earth Sciences, **96**: 623–638.

Ackerman, L., Jelínek, E., Medaris, G., Jr., Ježek, J., Siebel, W. & Strnad, L. (2009): Geochemistry of Fe-rich peridotites and associated pyroxenites from Horní Bory, Bohemian Massif: Insights into subduction-related melt–rock reactions. Chemical Geology, **259**: 152–167.

Anderson, A.J., Mayanovic, R.A. & Bajt, S. (1998): A micro-XAFS study of aqueous chlorozinc complexing up to 430 °C in saline fluid inclusions from the Knaumühle granitic pegmatite, Saxonian Granulite Massif, Germany. Canadian Mineralogist, **36**: 511–524.

Armbruster, T. (2002): Revised nomenclature of högbomite, nigerite, and taaffeite minerals. European Journal of Mineralogy, **14**: 389–395.

Aurisicchio, C., De Vito, C., Ferrini, V. & Orlandi, P. (2001): Nb-Ta oxide minerals from miarolitic pegmatites of the Baveno pink granite, NW Italy. Mineralogical Magazine, **65**: 509–522.

Baker, D.R. (1998): The escape of pegmatite dikes from granitic plutons: constraints from new models of viscosity and dike propagation. Canadian Mineralogist, **36**: 255–263.

Bergstřl, S. & Juve, G. (1988): Scandian ixiolite, pyrochlore and bazzite in granite pegmatite in terdal, Telemark, Norway. A contribution to the mineralogy and geochemistry of scandium and tin. Mineralogy and Petrology, **38**: 229–243.

Bouška, V. & Johan, Z. (1972): New data on písekite. Lithos, **5**: 93–103.

Breiter, K. (1998): P-rich muscovite granites – latest product of two-mica granites fractionation in the South Bohemian Pluton. In (Breiter, K., ed.): Genetic significance of phosphorus in fractionated granites, Peršlák, Czech Republic, September 1998. Excursion guide, 59–75.

Breiter, K. (2002): From explosive breccia to unidirectional solidification textures: magmatic evolution of a phosphorus- and fluorine-rich granite system (Podlesí, Krušné hory Mts., Czech Republic). Bulletin of the Czech Geological Survey, **77**: 67–92.

Breiter, K. & Scharbert, S. (1995): The Homolka magmatic centre – an example of late variscan ore bearing magmatism in the Southbohemian Batholith (Southern Bohemia, Northern Austria). Jahrbuch der Geologischen Bundesanstalt, **138**: 9–25.

Breiter, K. & Scharbert, S. (1998): Latest intrusions of the Eisgarn pluton (South Bohemia – Northern Waldviertel). Jahrbuch der Geologischen Bundesanstalt, **141**: 25–37.

Breiter, K., Beran, A., Buriánek, D., Cempírek, J., Dutrow, B., Henry, D., Novák, M. & Raimboult, L. (2003): Přibyslavice near Čáslav, tourmaline-muscovite orthogneiss, muscovite grante, pegmatite. In Novák, M. (ed.): International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Field trip guidebook, 77–90.

Breiter, K., Čopjaková, R., Gabašová, A. & Škoda, R. (2005a): Chemistry and mineralogy of orthogneisses in the northeastern part of the Moldanubicum. Journal of the Czech Geological Society, **50**: 81–94.

Breiter, K., Novák, M., Koller, F. & Cempírek, J. (2005b): Phosphorus – an omnipresent minor element in garnet of diverse textural types from leucocratic granitic rocks. Mineralogy and Petrology, **85**: 205–221.

Breiter, K., Škoda, R. & Starý, J. (2006): Mineralizace cínu, niobu a tantalu v Přibyslavicích u Čáslavi. Zprávy o geologických výzkumech v roce 2005. Praha: Czech Geological Survey, 102–107 (in Czech, with English summary).

Buriánek, D. & Novák, M. (2004): Morphological and compositional evolution of tourmaline from nodular granite at Lavičky near Velké Meziříčí, Moldanubicum, Czech Republic. Journal of the Czech Geological Society, **49**: 81–90.

Buriánek, D. & Novák, M. (2007): Compositional evolution and substitutions in disseminated and nodular tourmaline from leucocratic granites: Examples from the Bohemian Massif, Czech Republic. Lithos, **95**: 148–164.

Burkart, E. (1953): Moravské nerosty a jejich literatura. / Mährens Minerale und ihre Literatur. Praha: Nakladatelství ČSAV. 1005 p. (In German)

Burns, P.C., Novák, M. & Hawthorne, F.C. (1995): Fluorine-hydroxyl variation in hambergite: A crystal-structure study. Canadian Mineralogist, **33**: 1205–1213.

Carswell, D.A. & O'Brien, P.J. (1993): Thermobarometry and geotectonic significance of high pressure granulites: examples from the Moldanubian Zone of the Bohemian Massif in Lower Austria. Journal of Petrology, **34**: 427–459.

Čech, F. (1957): Priorit (blomstrandin) z Pozďátek u Třebíče. Časopis pro mineralogii a geologii, **2**: 346–348 (in Czech, with German summary).

Čech, F. (1985): Mineralogie žulových pegmatitů české části Českého masívu. Dissertation thesis, Charles Univ., Praha, Czech Republic, 333 p (in Czech).

Čech, F. & Paděra, K. (1958): Messelite aus dem Phosphatnestern im Granit bei Přibyslavice (Böhmen) und das Messelitproblem. Chemie der Erde, **19**: 436–449.

Čech, F., Rieder, M., Novák, F. & Novotný, J. (1978): Accessory nigerite in a granite from Central Bohemia, Czechoslovakia. Neues Jahrbuch für Mineralogie, Monatshefte, 337–346.

Cempírek, J. (2003): Minerální asociace a chemické složení dumortieritu z granitických pegmatitů. MSc thesis, Masaryk Univ., Brno, Czech Republic, 81 p (in Czech, with English summary).

Cempírek, J. & Novák, M. (2004a): Dumortierit a turmalín z abysálních pegmatitů od Vémyslic u Moravského Krumlova, gföhlská jednotka, moldanubikum. Acta Musei Moraviae, Scientiae geologicae, **89**: 45–54 (in Czech, with English Summary).

Cempírek, J. & Novák, M. (2004b): Abyssal pegmatite with olenite and dumortierite from Kutná Hora, Czech Republic; an example of fractionation in Li-poor Al,B-rich granitic system. In GAC/MAC Meeting, St. Catharines 2004, Abstracts Volume 29, 225.

Cempírek, J. & Novák, M. (2006a): Hydroxylherderit a sdružené berylofosfáty z pegmatitu Rožná-Borovina. Acta Musei Moraviae, Scientiae geologicae, **91**: 79–88 (in Czech, with English summary).

Cempírek, J. & Novák, M. (2006b): Mineralogy of dumortierite-bearing abyssal pegmatites at Starkoč and Běstvina, Kutná Hora Crystalline Complex. Journal of the Czech Geological Society, **51**: 259–270.

Cempírek, J., Novák, M. & Vávra, V. (1999): Hurlbutit z beryl-columbitového pegmatitu v Kostelním Vydří u Telče, západní Morava. Acta Musei Moraviae, Scientiace geologicae, **84**: 45–48 (in Czech, with English summary).

Cempírek, J., Buriánek, D., Beran, A. & Novák, M. (2003): Locality no. 9: Starkoč near Čáslav. Garnet-biotite gneiss to migmatite, abyssal barren pegmatite. In Novák, M. (ed.): International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Field trip guidebook, 71–76.

Cempírek, J., Novák, M., Ertl, A., Hughes, J.M., Rossman, G.R. & Dyar, M.D. (2006): Fe-bearing olenite with tetrahedrally coordinated Al from an abyssal pegmatite at Kutná Hora, Czech Republic: structure, crystal chemistry, optical spectra and Xanes spectra. Canadian Mineralogist, **44**: 23–30.

Cempírek, J., Novák, M. & Dolníček, Z. (2009): Grandidierite-ominelite, boralsilite and Fe-werdingite from the Bory Granulite Massif, Czech Republic. In Granulites & Granulites 2009 – Granulites, partial melting and rheology of orogenic lower crust, Hrubá Skála, Czech Republic. Book of abstract, 10.

Černý, P. (1956): Srůsty xenotimu a zirkonu z Drahonína. Spisy přírodovědecké fakulty Masarykovy Univerzity, **376**: 293–306 (in Czech, with English and Russian summary).

Černý, P. (1991a): Rare-element granitic pegmatites. I. Anatomy and internal evolution of pegmatite deposits. Geoscience Canada, **18**: 49–67.

Černý, P. (1991b): Rare-element granitic pegmatites. II. Regional to global environments and Petrogenesis. Geoscience Canada, **18**: 68–81.

Černý, P. & Ercit, T.S. (2005): Classification of granitic pegmatites. Canadian Mineralogist, **43**: 2005–2026.

Černý, P. & Němec, D. (1995): Pristine vs. contaminated trends in Nb, Ta-oxide minerals of the Jihlava Pegmatite district. Mineralogy and Petrology, **55**: 117–130.

Černý, P. & Novák, M. (1992): Locality No.2: Věžná near Nedvědice, a pegmatite dike of the beryl-columbite subtype penetrating serpentinite. In Novák, M. & Černý, P. (eds): International symposium on mineralogy, petrology and geochemistry of granitic pegmatites Lepidolite 200, Nové Město na Moravě, Czech Republic. Field trip guidebook, 27–32.

Černý, P. & Povondra, P. (1966): Beryllian cordierite from Věžná: (Na,K) + Be = Al. Neues Jahrbuch für Mineralogie, Monatshefte, 36–44.

Černý, P., Hawthorne, F.C., Laflamme, J.H.G. & Hinthorne, J.R. (1979): Stibiobetafite, a new member of the pyrochlore group from Věžná, Czechoslovakia. Canadian Mineralogist, **17**: 583–588.

Černý, P., Smith, J.V., Mason, R.A. & Delaney, J.S. (1984): Geochemistry and petrology of feldspar crystallization in the Věžná pegmatite. Canadian Mineralogist, **22**: 631–651.

Černý, P., Staněk, J., Novák, M., Baadsgaard, H., Rieder, M., Ottolini, L., Kavalová, M. & Chapman, R. (1995): Chemical and structural evolution of micas at the Rožná and Dobrá Voda pegmatites, Czech Republic. Mineralogy and Petrology, **55**: 177–202.

Černý, P., Chapman, R., Schreyer, W., Ottolini, L., Bottazzi, P. & McCammon, C. (1997): Lithium in sekaninaite from the type locality, Dolní Bory, Czech Republic. Canadian Mineralogist, **35**: 167–173.

Černý, P., Chapman, R., Teertstra, D.K. & Novák, M. (2003): Rubidium- and cesium-dominant micas in granitic pegmatites. American Mineralogist, **88**: 1832–1835.

Černý, P., Novák, M., Chapman, R. & Ferreira, K.J. (2007): Subsolidus behavior of niobian rutile from the Písek region, Czech Republic: a model for exsolution in W- and Fe^{2+}>>Fe^{3+}-rich phases. Journal of the Czech Geological Society, **52**: 143–159.

Chen, F. & Siebel, W. (2004): Zircon and titanite geochronology of the Fürstenstein granite massif, Bavarian Forest, NW Bohemian Massif: Pulses of the late Variscan magmatic activity. European Journal of Mineralogy, **16**: 777–788.

Cooper, M., Hawthorne, F.C. & Černý, P. (2000): Refinement of the crystal structure of cyrilovite from Cyrilov, Western Moravia, Czech Republic. Journal of the Czech Geological Society, **45**: 95–100.

Dallmeyer, R.D., Franke, W., Weber, K. (1995): Pre-Permian geology of central and eastern Europe. Berlin: Springer-Verlag, 593 p.

Dingwell, D.B., Pichavant, M. & Holtz, F. (1996): Experimental studies of boron in granitic melts. In Grew, E.S. & Anovitz, L.M. (eds): Boron: Mineralogy, petrology and geochemistry (Reviews in Mineralogy and Geochemistry, **33**). Washington (D.C.): Mineral. Soc. Am., 330–385.

Dosbaba, M. & Novák, M. (2007): Quartz replacement by sepiolite at the Věžná I pegmatite, Czech Republic; An initial stage of a complex desilicification process. Memórias (Universidade do Porto, Faculdade de Ciências), **8**: 38–39.

Duda, J. (1986): Pegmatites in the Bory granulite massif. Sborník geologických Věd, Ložisková geologie a mineralogie, **27**: 157–202.

Ertl, A., Schuster, R., Prowatke, S., Brandstätter, F., Ludwig, T., Berndhardt, H-J., Koller, F. & Hughes, J.M. (2004): Mn-rich tourmaline and fluorapatite in a variscan pegmatite from Eibenstein an der Thaya, Bohemian massif, Lower Austria. European Journal of Mineralogy, **16**: 551–560.

Faryad, S.W. (2009): The Kutná Hora Complex (Moldanubian zone, Bohemian Massif): A composite of crustal and mantle rocks subducted to HP/UHP conditions. Lithos, **109**: 193–208.

Fiala, F. (1954): Dumortierit od Miskovic. Sborník Národního Muzea, **10**: 3–38 (in Czech, with English summary).

Filip, J., Kolitsch, U., Novák, M. & Schneeweiss, O. (2006): The crystal structure of near-end-member ferroaxinite from an iron-contaminated primitive pegmatite at Malešov, Czech Republic. Canadian Mineralogist, **44**: 1157–1170.

Finger, F., Roberts, M.P., Haunschmid, B., Schermaier, A. & Steyrer, H.P. (1997): Variscan granitoids of central Europe: their typology, potential sources and tectonothermal relations. Mineralogy and Petrology, **61**: 67–96.

Foit, F.F. & Rosenberg, P.F. (1977): Coupled substitutions in the tourmaline group. Contributions to Mineralogy and Petrology, **62**: 109–127.

Foley, S.F., Venturelli, G., Green, D.H. & Toscani, L. (1987): The ultrapotassic rocks; characteristics, classification, and constraints for petrogenetic models. Earth Science Reviews, **24**: 81–134.

Fuchs, G. & Matura, A. (1976): Zur Geologie des Kristallins der südlichen Böhmischen Masse. Jahrbuch der Geologischen Bundesanstalt, **119**: 1–43.

Gebauer, D. & Friedl, G. (1994): A 1.38 Ga protolith age for the Dobra Orthogneiss (Moldanubian Zone of the southern Bohemian Massif, NE-Austria): evidence from ion-microprobe (SHRIMP) dating of zircon. Journal of the Czech Geological Society, **39**: 34–35.

Glodny, J., Grauert, B., Fiala, J., Vejnar, Z. & Krohe, A. (1998): Metapegmatites in the western Bohemian massif: ages of crystallisation and metamorphic overprint, as constrained by U-Pb zircon, monazite, garnet, columbite and Rb-Sr muscovite data. Geologische Rundschau, **87**: 124–134.

Goliáš, V., (2002): Thorium Occurrences in the Czech Republic and their Mineralogy. In Křibek, B. & Zeman, J. (eds): Uranium deposits – from their genesis to the environmental aspects. Prague. Proceedings: 54–56.

Grew, E.S., Yates, M.G., Barbier, J., Shearer, C.K., Sheraton, J.W., Shiraishi, K. & Motoyoshi, Y. (2000): Granulite-facies beryllium pegmatites in the Napier Complex in Khmara and

Amundsen bays, western Enderby Land, East Antarctica. Polar Geoscience, **13**: 1–40.

Hanson, S.L., Simmons, W.B., Webber, K.W. & Falster, A.U. (1992): Rare-earth-element mineralogy of granitic pegmatites in the Trout Creek Pass district, Chaffee county, Colorado. Canadian Mineralogist, **30**: 673–686.

Hawthorne, F.C. (1996): Bond-valence constraints on the chemical composition of tourmaline. Canadian Mineralogist, **40**: 789–797.

Dutrow, B. & Henry, D. J. (2000) Complexly zoned fibrous tourmaline: A record of evolving magmatic and hydrothermal fluids. Canadian Mineralogist, 38, 131 –143.

Holub, F.V., Cocherie, A. & Rossi, P. (1997a): Radiometric dating of granitic rocks from the Central Bohemian Plutonic Complex (Czech Republic): constraints on the chronology of thermal and tectonic events along the Moldanubian–Barrandian boundary. Comptes rendus de l'Académie des sciences, Sciences de la terre et des plančtes, **325**: 19–26.

Holub, F.V., Machart, J. & Manová, M. (1997b): The Central Bohemian Plutonic Complex: geology, chemical composition and genetic interpretation. Sborník Geologických Věd, řada LG, **31**: 27–50.

Janoušek, V., Bowes, D.R., Rogers, G., Farrow, C.M. & Jelínek, E. (2000): Modelling diverse processes in the petrogenesis of a composite batholith: the Central Bohemian Pluton, Central European Hercynides. Journal of Petrology, **41**: 511–543.

Jiang, S-Y., Yang, J.H., Novák, M. & Selway, J.B. (2003): Chemical and boron isotopic compositions of tourmaline from the Lavičky leucogranite, Czech Republic. Geochemical Journal, **37**: 545–556.

Jolliff, B.L., Papike, J.J. & Shearer, C.K. (1987): Tourmaline as a recorder of pegmatite evolution; Bob Ingersoll Pegmatite, Black Hills, South Dakota. American Mineralogist, **71**: 472 –500.

Kadlec, T. (2007): Tourmaline as an indicator of degree of contamination in granitic pegmatites from Vlastějovice near Sázava. MSc. thesis, Masaryk Univ., Brno, Czech Republic.

Karsten, D.L.G. (1792): Aus einem Schreiben von Hrn. Bergrath Karsten in Berlin. Bergmannisches Journal, **2**: 80.

Klečka M., Machart, J. & Pivec, E. (1992): Locality No.10: Křížovská Hora quarry near Vlašim, a Pre-Variscan tourmaline-bearing two-mica orthogneiss (Blaník type). In Novák, M. & Černý, P. (eds): International symposium on mineralogy, petrology and geochemistry of granitic pegmatites Lepidolite 200, Nové Město na Moravě, Czech Republic. Field trip guidebook, 69–74.

Kotková, J. (2007): High-pressure granulites of the Bohemian Massif: recent advances and open questions. Journal of Geosciences, **52**: 45–71.

Kotková, J., Novák, M. & Povondra, P. (2003a): Locality No. 6: Horní Bory near Velké Meziříčí. Granulite, migmatite and granitic pegmatite. In Novák, M. (ed.): International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Field trip guidebook, 47–52.

Kotková, J., Schaltegger, U. & Leichmann, J. (2003b): 338-335 Ma old intrusions in the E Bohemian massif – a relic of the orogen-wide durbachitic magmatism in European Variscides. Journal of the Czech Geological Society, **48**: 80–81.

Koutek, J. (1950): Ložisko magnetovce skarnového typu u Vlastějovic v Posázaví. Rozpravy Československé Akademie Věd, **60**: 1–30 (in Czech, with French summary).

Krejčí, A. (1923): Písekit, nový radioaktivní nerost nebo klamotvar. Časopis Min. Geol., **1**: 2–5 (in Czech, with French summary).

Kröner, A., Wendt, I., Liew, T.C., Compston, W., Todt, W., Fiala, J., Vaňková, A. & Vaněk, J. (1988): U-Pb zircon and Sm-Nd model ages of high-grade Moldanubian metasediments, Bohemian Massif, Czechoslovakia. Contributions to Mineralogy and Petrology, **99**: 257–266.

Liang, J.-J., Hawthorne, F.C., Novák, M., Černý, P. & Ottolini, L. (1995): Crystal-structure refinement of boromuscovite polymorphs using a coupled Rietveld-static-structure-energy minimization method. Canadian Mineralogist, **33**: 859–865.

London, D. (2008): Pegmatites. (Canadian Mineralogist, Spec. Publ. **10**). Ottawa: Mineral. Assoc. Can., 347 p.

London, D., Morgan, G.B. & Wolf, M.B. (1996): Boron in granitic rocks and their contact aureoles. In Grew, E.S. & Anovitz, L.M. (eds): Boron: Mineralogy, petrology and geochemistry (Reviews in Mineralogy and Geochemistry, **33**). Washington (D.C.): Mineral. Soc. Am., 299–330.

Losert, J. (1956): Dumortierity z pegmatitů a migmatitů v širším okolí Kutné Hory. Rozpravy Československé Akademie Věd, **66**: 1–44 (in Czech, with English summary).

Martin, R.F. & De Vito, C. (2005): The pattern of enrichment in felsic pegmatites ultimately depend on tectonic setting. Canadian Mineralogist, **43**: 2027–2048.

Martin-Izard, A., Paniagua, A., Moreiras, D., Acevedo, R.D. & Marcos-Pascual, C. (1995): Metasomatism at a granitic pegmatite – dunite contact in Galicia: the Franqueira occurrence of chrysoberyl (alexandrite), emerald, and phenacite. Canadian Mineralogist, **33**: 775–792.

Matte, Ph., Maluski, H., Rajlich, P. & Franke, W. (1990): Terrane boundaries in the Bohemian Massif: Result of large-scale Variscan shearing. Tectonophysics, **177**: 151–170.

Medaris, L.G. Jr., Beard, B.L., Johnson C.M., Valley J.W., Spicuzza M.J., Jelínek E. & Mísař Z. (1995): Garnet pyroxenite and eclogite in the Bohemian Massif: geochemical evidence for Variscan recycling of subducted lithosphere. Geologische Rundschau, **84**: 489–505.

Mrázek Z. & Vrána S. (1984): Highly aluminian titanite from a plagioclase-fluorite pegmatite in skarn at Vlastějovice, Czechoslovakia. Neues Jahrbuch für Mineralogie, Monatshefte, 193–196.

Mücke, A. (2000): Die Erzmineralien und deren Paragenesen im Pegmatit von Hagendorf-Süd, Oberpfalz. Aufschluss, **51**: 11–24.

Munoz, J.L. (1984): F-OH and Cl-OH exchange in micas with applications to hydrothermal ore deposits. In Bailey, S.W. (ed.): Micas (Reviews in Mineralogy and Geochemistry, **13**). Washington (D.C.): Mineral. Soc. Am., 469–493.

Nahodilová, R., Faryad, S.W., Pertoldová, J., Konopásek, J. & Štědrá, V. (2005): HP melting and its relationship to the granulite facies metamorphism – an example of the 'Gföhl Nappe' in the Kutná Hora Crystalline Complex. Geolines, **19**: 86–87.

Němec, D. (1973): Das Vorkommen der Zn-Spinelle in der Böhmischen Masse. Tschermaks Mineralogische und Petrographische Mitteilungen, **19**: 95–109.

Němec, D. (1978): Zink im Staurolith. Chemie der Erde, **37**: 307–314.

Němec, D. (1981): Ein Pegmatit mit Li-Mineralisierung von Dolní Bory, Westmähren (ČSSR). Chemie der Erde, **40**: 146–177.

Němec, D. (1998): The Rožná pegmatite field, western Moravia (Czech Republic). Chemie der Erde, **58**: 233–246.

Novák, M. (1999): Cassiterite and tusionite as monitors of B and Sn behaviour in the elbaite pegmatite at Řečice near Nové Město na Moravě, western Moravia, Czech Republic. Neues Jahrbuch für Mineralogie, Monatshefte, 481–493.

Novák, M. (2000): Compositional pathways of tourmaline evolution during primary (magmatic) crystallization in complex (Li) pegmatites of the Moldanubicum, Czech Republic. Memorie della

Societŕ Italiana di Scienze Naturali e del Museo Civico di Storia Naturale di Milano, **30**: 45–56.

Novák, M. (2005): Granitické pegmatity Českého masivu (Česká republika); mineralogická, geochemická a regionální klasifikace a geologický význam. Acta Musei Moraviae, Scientiae geologicae, **90**, 3–74 (in Czech, with English summary).

Novák, M. (2007): Contamination in granitic pegmatites, examples from the Moldanubicum, Czech Republic. In Granitic Pegmatites: The state of the art – International Symposium. Universidade do Porto. Faculdade de Cięncias, Memórias, **9**: 9 –12.

Novák, M. & Buriánek, D. (2003): Distinctive compositional trends in Fe-rich tourmaline from granitic rocks; crystal-structural role of Li and F. In International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Book of Abstracts, 53–54.

Novák, M. & Černý, P. (1998): Niobium-tantalum oxide minerals from complex pegmatites in the Moldanubicum, Czech Republic; Primary versus secondary compositional trends. Canadian Mineralogist, **36**: 659–672.

Novák, M. & Černý, P. (2001): Distinctive compositional trends in columbite-tantalite from two segments of the lepidolite pegmatite at Rožná, western Moravia, Czech Republic. Journal of the Czech Geological Society, **46**: 1–8.

Novák, M. & Cícha, J. (2009): Klasifikace granitických pegmatitů Písecka. Minerál, Special issue 2009, 8–19 (in Czech).

Novák, M. & Diviš, K. (1996): Compositional trends in manganocolumbite from the Puklice I pegmatite, western Moravia, Czech Republic. Journal of the Czech Geological Society, **41**: 1–6.

Novák, M. & Hyršl, J. (1992): Locality No.3: Vlastějovice near Zruč nad Sázavou, pegmatites with fluorite penetrating skarn. In Novák, M. & Černý, P. (eds): International symposium on mineralogy, petrology and geochemistry of granitic pegmatites Lepidolite 200, Nové Město na Moravě, Czech Republic. Field trip guidebook, 33–37.

Novák, M. & Povondra, P. (1995): Elbaite pegmatites in the Moldanubicum: a new subtype of the rare-element class. Mineralogy and Petrology, **55**: 159–176.

Novák, M. & Selway, J.B. (1997): Locality No. 1: Rožná near Bystřice nad Pernštejnem, Hradisko hill, a large lepidolite subtype pegmatite dike. In Novák, M. & Selway, J.B. (eds): International Symposium Tourmaline 1997, Nové Město na Moravě, Czech Republic. Field Trip Guidebook, 23–38.

Novák, M. & Šrein, V. (1998): Niobian cesstibtantite from the Dobrá Voda lepidolite pegmatite, Western Moravia, Czech Republic. Neues Jahrbuch für Mineralogie, Monatshefte, 354–360.

Novák, M. & Taylor, M.C. (2000): Foitite: Formation during late stages of evolution of complex pegmatites at Dobrá Voda, Czech Republic, and Pala, California, USA. Canadian Mineralogist, **38**: 1399–1408.

Novák, M., Korbel, P. & Odehnal, F. (1991): Pseudomorphs of bertrandite and epididymite after beryl from Věžná, Western Moravia, Czechoslovakia. Neues Jahrbuch für Mineralogie, Monatshefte, 473–480.

Novák, M., Černý, P., Čech, F. & Staněk, J. (1992): Granitic pegmatites in the territory of the Bohemian and Moravian Moldanubicum. In Novák, M. & Černý, P. (eds): International symposium on mineralogy, petrology and geochemistry of granitic pegmatites Lepidolite 200, Nové Město na Moravě, Czech Republic. Field trip guidebook, 11–20.

Novák, M., Selway, J.B., Korbel, P. & Šarbach, M. (1997a): Locality No. 4: Bližná near Černá v Pošumaví, elbaite subtype pegmatite penetrating marble with exomorphic tourmaline. In Novák, M. & Selway, J.B. (eds): International Symposium Tourmaline 1997, Nové Město na Moravě, Czech Republic. Field Trip Guidebook, 55–70.

Novák, M., Selway, J.B. & Staněk, J. (1997b): Locality No. 10: Myšenec near Protivín, barren pegmatite with giant tourmaline aggregates. In Novák, M. & Selway, J.B. (eds): International Symposium Tourmaline 1997, Nové Město na Moravě, Czech Republic. Field Trip Guidebook, 105–110.

Novák, M., Selway, J.B. & Uher, P. (1997c): Locality No. 6: Lavičky near Velké Meziříčí, quartz-tourmaline orbicules in leucocratic two-mica granite tourmaline in barren pegmatite and hydrothermal quartz-tourmaline veins. In Novák, M. & Selway, J.B. (eds): International Symposium Tourmaline 1997, Nové Město na Moravě, Czech Republic. Field Trip Guidebook, 77–84.

Novák, M., Burns, P.C. & Morgan, G.B.VI (1998a): Fluorine variation in hambergite from granitic pegmatites. Canadian Mineralogist, **36**: 441–446.

Novák, M., Černý, P., Kimbrough, D.L., Taylor, M.C. & Ercit, T.S. (1998b): U-Pb Ages of monazite from granitic pegmatites in the Moldanubian Zone and their geological implications. Acta Universitatis Carolinae, Geologica, **42**: 309–310.

Novák, M., Houzar, S. & Pfeiferová, A. (1998c): Přehled mineralogie, petrografie a historie klasické lokality lepidolitového pegmatitu v Rožné u Bystřice nad Pernštejnem, západní Morava. Acta Musei Moraviae, Scientiae geologicae, **83**: 3–48. (in Czech, with English summary)

Novák, M., Černý, P, Cooper, M, Hawthorne, F.C., Ottolini, L., Xu, Z. & Liang, J-J. (1999a): Boron-bearing $2M_1$ polylithionite and $2M_1$ + 1M boromuscovite from an elbaite pegmatite at Řečice, western Moravia, Czech Republic. European Journal of Mineralogy, **11**: 669–678.

Novák, M., Černý, P. & Selway, J.B. (1999b): The zinnwaldite-masutomilite-elbaite pegmatite at Kracovice from the Třebíč durbachite massif – a complex pegmatite related to the NYF family. Canadian Mineralogist, **37**: 815–816.

Novák, M., Selway, J.B., Černý, P. & Hawthorne, F.C. (1999c): Tourmaline of the elbaite-dravite series from an elbaite-subtype pegmatite at Bližná, southern Bohemia, Czech Republic. European Journal of Mineralogy, **11**: 557–568.

Novák, M., Sejkora, J. & Cooper, M.A. (2000): Cyrilovite from Cyrilov, western Moravia, Czech Republic; new data on the type material. Journal of the Czech Geological Society, **45**: 1010–1016.

Novák, M., Černý, P., Povondra, P. & Škoda, R. (2003): Locality No. 4: Věžná near Nedvědice. Beryl pegmatite. In Novák, M. (ed.): International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Field trip guidebook, 31–37.

Novák, M., Černý, P., Cempírek, J., Šrein, V. & Filip, J. (2004a): Ferrotapiolite as pseudomorph of stibiotantalite from the Laštovičky lepidolite pegmatite, Czech Republic; an example of hydrothermal alteration at constant Ta/(Ta+Nb). Canadian Mineralogist, **42**: 1117–1128.

Novák, M., Povondra, P. & Selway, J.B. (2004b): Schorl–oxy-schorl to dravite–oxy-dravite tourmaline from granitic pegmatites; examples from the Moldanubicum, Czech Republic. European Journal of Mineralogy, **16**: 323–333.

Novák, M., Johan, Z., Škoda, R., Černý, P., Šrein, V. & Veselovský, F. (2008): Primary oxide minerals in the system WO_3–Nb_2O_5–TiO_2–Fe_2O_3–FeO and their breakdown products from the pegmatite No. 3 at Dolní Bory, Hatě, Czech Republic. European Journal of Mineralogy, **20**: 489–499.

1138L

NOVOTNÝ, M. & STANĚK, J. (1953): Nový minerál, fosforečnan cyrilovit. Práce Moravskoslezské akademie věd přírodních, **25**: 325–336 (in Czech, with English and Russian summary).

NOVOTNÝ, M. & ŠTELCL, J. (1951): Pegmatity z Hradiska a Boroviny u Rožné n. Pernšt. Práce Moravskoslezské akademie věd přírodních, **23**: 259–274 (in Czech, with English and Russian summary).

PAVLÍČEK, V., BREITER, K. & ŠKODA, R. (2009): Pegmatit beryl-kolumbitového typu ze Šejb v Novohradských horách. Zprávy o geologických výzkumech v roce 2008. Praha: Czech Geological Survey, 185–188 (in Czech, with English summary).

POVONDRA, P. (1981): The crystal chemistry of tourmalines of the schorl-dravite series. Acta Universitatis Carolinae, Geologica, 223–264.

POVONDRA, P., ČECH, F. & STANĚK, J. (1985): Crystal chemistry of elbaites from some pegmatites of the Czech Massif. Acta Universitatis Carolinae, Geologica, 1–24.

POVONDRA, P., PIVEC, E., ČECH, F., LANG, M., NOVÁK, F., PRACHAŘ, I. & ULRYCH, J. (1987): Přibyslavice peraluminous granite. Acta Universitatis Carolinae, Geologica, 183–283.

POVONDRA, P., STAŇKOVÁ, J. & STANĚK, J. (1992): CO_2-bearing cordierite of Moldanubian leptynite rock series from Horní Bory, Czech Republic. Acta Universitatis Carolinae, Geologica, 331–349.

POVONDRA, P., LANG, M., PIVEC, E. & ULRYCH, J. (1998): Tourmaline from the Přibyslavice peraluminous alkali-feldspar granite, Czech Republic. Journal of the Czech Geological Society, **43**: 3–8.

PRACHAŘ, I., POVONDRA, P. & NOVÁK, F. (1983): Manganese-rich siderite from granite at Přibyslavice near Čáslav. Acta Universitatis Carolinae, Geologica, 13–25.

RAADE, G., SÆBØ, AUSTRHEIM, H. & KRISTIANSEN, R. (1993): Kuliokite-(Y) and its alteration products kainosit-(Y) and kamphaugit-(Y) from granite pegmatite in Tørdal, Norway. European Journal of Mineralogy, **5**: 691–698.

RAADE, G., BERNHARD, F. & OTTOLINI, L. (2004) Replacement textures involving four scandium silicate minerals in the Heftetjern granitic pegmatite, Norway. European Journal of Mineralogy, **16**: 945–950.

REZEK K. & KRYST P. (1985): Předběžná zpráva o výskytu nerostů U-Th, Ti-Zr a Nb-Ta v pegmatitu na Holém vrchu u Vlastějovic, zsz. od. Ledče nad Sázavou. Časopis pro Mineralogii a Geologii, **30**: 434 (in Czech).

SCHARIZER, R. (1888): Über die chemische Constitution der verschiedenfarbigen Glimmer des Pegmatit-granites von Schüttenhofen. Zeitschritt für Kristallografie, **13**: 449–473.

SCHARIZER, R. (1889): Über die chemische Constitution und über die Farbe der Turmaline von Schüttenhofen. Zeitschritt für Kristallografie, **15**: 337–365.

SEJKORA, J., LITOCHLEB, J., EXNAR, P., ČERNÝ, P. & ČECH, F. (1998): Některá fyzikálně-chemická data pro růžový beryl (morganit) z píseckých pegmatitů. Bulletin of the Czech Geological Survey, **73**: 347–350 (in Czech, with English summary).

SEKANINA, J. (1928): Nerosty moravských pegmatitů. Časopis Moravského zemského musea, **26**: 113–224 (in Czech, with German summary).

SEKANINA, J. (1933): Příspěvky k mineralogii moravských pegmatitů. Spisy přírodovědecké fakulty Masarykovy University, **180**: 3 –26 (in Czech, with German summary).

SEKANINA, J. (1946): Nerosty a horniny v území nezi Nedvědicí a Rožnou. Sborník Klubu přírodovědeckého v Brně, **26**: 99–113. (in Czech, with French summary).

SELWAY, J.B., NOVÁK, M., HAWTHORNE, F.C., ČERNÝ, P., OTTOLINI, L. & KYSER, T.K. (1998): Rossmanite $\square LiAl_2Al_6(BO_3)_3Si_6O_{18}(OH)_4$, a new alkali-deficient tourmaline: Description and crystal structure. American Mineralogist, **83**: 894–900.

SELWAY, J.B., NOVÁK, M., ČERNÝ, P. & HAWTHORNE, F.C. (1999): Compositional evolution of tourmaline in lepidolite-subtype pegmatites. European Journal of Mineralogy, **12**: 569–584.

ŠKODA, R. & NOVÁK, M. (2007): Y,REE,Nb,Ta,Ti-oxide (AB_2O_6) minerals from REL-REE euxenite-subtype pegmatites of the Třebíč Pluton, Czech Republic; substitutions and fractionation trends. Lithos, **95**: 43–99.

ŠKODA, R., NOVÁK, M. & HOUZAR, S. (2006): Granitické NYF pegmatity třebíčského plutonu. Acta Musei Moraviae, Scientiae geologicae, **91**: 129–176 (in Czech, with English summary).

ŠKODA, R., STANĚK, J. & ČOPJAKOVÁ, R. (2007): Minerální asociace fosfátových nodulí granitického pegmatitu od Cyrilova u Velkého Meziříčí, Moldanubikum; část I – primární a exsoluční fáze. Acta Musei Moraviae, Scientiae geologicae, **92**: 59–74 (in Czech, with English summary).

SLAVÍK, F. (1904): Mineralogické zprávy ze západní Moravy II. Rozpravy české akademie věd, **13(35)**: 1–10 (in Czech).

STANĚK, J. (1954): Petrografie a mineralogie pegmatitových žil u Dolních Borů. Práce Brněnské Základny Československé Akademie Věd, **26**: 1–43 (in Czech, with German summary).

STANĚK, J. (1968): Triplit, kasiterit a topaz z pegmatitu od Rousměrova na západní Moravě. Folia Fac. Sci. Nat. Univ. Purk. Brun., **14**: 71–81. (in Czech, with English and Russian summary)

STANĚK, J. (1973a): Mineral paragenesis of the new lithium-bearing pegmatite at Laštovičky, western Moravia, Czechoslovakia. Scripta Facultatis Scientiarum Naturalium Universitatis Purkynianae Brunensis, **3**: 1–14.

STANĚK, J. (1973b): Phenakite from Třebíč, Czechoslovakia. Časopis Moravského muzea, vědy přírodní, **58**: 49–52.

STANĚK, J. (1991): Parageneze minerálů pegmatitových žil z Hatí u Dolních Borů na západní Moravě. Acta Musei Moraviae, Scientiae naturalis, **76**: 19–49 (in Czech, with English summary).

STANĚK, J. (1997): Asociace minerálů významnějších pegmatitových žil v Hatích u Dolních Borů na západní Moravě. Acta Musei Moraviae, Scientiae naturalis, **82**: 3–19 (in Czech, with English summary).

STANĚK, J. (2008): Die Mineralien aus den Pegmatitgängen von Dolní Bory-Hatě, Tschechische Republik. Aufschluss, **59**: 81–102.

STANĚK, J. & MIŠKOVSKÝ, J. (1975): Sekaninaite, a new mineral of the cordierite series, from Dolní Bory, Czechoslovakia. Scripta Facultatis Scientiarum Naturalium Universitatis Purkynianae Brunensis, **5**: 21–30.

STAŇKOVÁ, J. (1982): "Dist-sillimanite": its importance for assessment of polyphase metamorphism in the leptynite body near Bory, Czechoslovakia. Krystalinikum, **16**: 53–66.

STRUNZ, H. (1956): Identität von Avelionit und Cyrilovit. Neues Jahrbuch für Mineralogie, Monatshefte, 187–189.

SULOVSKÝ, P. (2000): Srovnání chemismu třebíčského durbachitu a jiných durbachitů. Geologické Výzkumy na Moravě a ve Slezsku v roce 1999, 135–140 (in Czech, with English summary).

SYNEK, J. & OLIVIEROVÁ, D. (1993): Terrane character of the NE border of the Moldanubian Zone: the Kutná Hora Crystalline Complex, Bohemian Massif. Geologische Rundschau, **82**: 566–582.

TEERTSTRA, D.K., ČERNÝ, P. & NOVÁK, M. (1995): Compositional and textural evolution of pollucite in rare-element pegmatites of the Moldanubicum. Mineralogy and Petrology, **55**: 37–52.

TOLLMANN, A. (1982): Großräumiger Variszischer Deckenbau im Moldanubikum und neue Gedanken zum Variszikum Europas. Geotektonische Forschungen, **64**: 1–91.

Van Lichtervelde, M., Linnen, R.L., Salvi, S. & Beziat, D. (2006): The role of metagabbro rafts on tantalum mineralization in the Tanco granitic pegmatite, Manitoba. Canadian Mineralogist, **44**: 625–644.

Vavřín, I. (1962): Pegmatity magdalénského skarnového ložiska u Vlastějovic nad Sázavou. Sborník Národního Muzea (Praha), Řada B, **18**: 89–105 (in Czech, with English summary).

Vížďa, P. (2003): Mineralogické studium kasiteritů různé geneze z lokalit ČR. MSc. thesis, Masaryk Univ., Brno, Czech Republic (in Czech, with English summary).

Vollstädt, H. & Weiss, S. (1991): Mineralfundstellen Sächsisches Erzgebirge. München: Weise Verlag, 127 p.

Vrána, S. & Kröner, A. (1995): Pb-Pb zircon ages for tourmaline alkali-feldspar orthogneiss from Hluboká nad Vltavou in southern Bohemia. Journal of the Czech Geological Society, **40**: 127–135.

Vrána, S., Štědrá, V. & Fišera, M. (2005): Petrology and geochemistry of the Běstvina granulite body metamorphosed at eclogite facies conditions, Bohemian Massif. Journal of the Czech Geological Society, **50**: 95–106.

Vrba, K. (1888): O některých minerálech píseckých. Věstník Královské české společnosti nauk, **33**: 554–575 (in Czech).

Vrba, K. (1894): O minerálech beryllnatých okolí Píseckého. Rozpravy české akademie věd císaře Františka Josefa, **3(12)**: 1–16 (in Czech).

Wendt, I., Kröner, A., Fiala, J. & Todt, W. (1993): Evidence from zircon dating for existence of approximately 2.1 Ga old crystalline basement in southern Bohemia, Czech Republic. Geologische Rundschau, **82**: 42–50.

Wise, M.A. (1995): Trace element chemistry of lithium-rich micas from rare-element granitic pegmatites. Mineralogy and Petrology, **55**: 203–215.

Žáček, V. (1997): Compositional evolution of garnet in the regionally metamorphosed skarn, Vlastějovice, evidence of the preservation of early stages pre-dating regional metamorphism. Bulletin of the Czech Geological Survey, **72(1)**: 37–48.

Žáček, V. & Povondra, P. (1991): Minerals from the skarn at Vlastějovice ner Ledeč nad Sázavou, Central Bohemia, Czechoslovakia. Acta Universitatis Carolinae, Geologica, 71–101.

Žáček, V., Novák, M., Raimboult, L., Zachariáš, J. & Ackerman, L. (2003): Locality No. 8: Vlastějovice near Ledeč nad Sázavou. Fe-skarn, barren fluorite pegmatite. In Novák, M. (ed.): International symposium on light elements in rock forming minerals LERM 2003, Nové Město na Moravě, Czech Republic. Field trip guidebook, 61–70.

Žák, J., Holub, F.V. & Verner, K. (2005). Tectonic evolution of a continental magmatic arc from transpression in the upper crust to exhumation of mid-crustal orogenic root recorded by episodically emplaced plutons: the Central Bohemian Plutonic Complex (Bohemian Massif). International Journal of Earth Sciences (Geologische Rundschau), **94**: 385–400.

Zoubek, V. (ed.) (1988): Precambrian in younger fold belts. Chichester – Singapore: Wiley and Sons, 885 p.

Appendix – Itinerary for IMA2010 CZ2 Field trip

(mineralogical collections – small caps, sightseeing – *in italics*)

Saturday, August 28, 2010 (Day 1)

- Arrival by train from Budapest to Brno at about 2-3 pm
- Brno (Museum stop 1: Moravian Museum, mineralogical collection, special exhibition to IMA Congress: Granitic pegmatites in Czech Republic; introduction to the excursion)
- Skalský dvůr near Nové Město na Moravě (accommodation), arrival about 7 pm, about 80 km by bus

Sunday, August 29, 2010 (Day 2)

- Skalský dvůr, departure 8.30 am
- Rožná (Field stop 1: Classical locality of lepidolite pegmatite, type locality of lepidolite and rossmanite)
- *Pernštejn (medieval castle – visit)*
- Oslavice (Field stop 2: NYF allanite and euxenite pegmatites in syenogranite)
- Horní Bory (Field stop 3: abyssal and subabyssal pegmatites)
- Skalský dvůr (dinner, accommodation), arrival about 7 pm, about 100 km by bus

Monday, August 30, 2010 (Day 3)

- Skalský dvůr, departure 9.00 am
- *Žďár nad Sázavou (church, UNESCO site – visit)*
- Starkoč (Field stop 4: Abyssal pegmatite with dumortierite, olenite and staurolite)
- *Kutná Hora* (Museum stop 2: Kutná Hora Museum, mineralogical collection, *medieval mining city UNESCO site – visit*)
- Přibyslavice (Field stop 5: Leucocratic granite, pegmatitic rocks with large crystals of almandine, tourmaline, primary Fe-Mn phosphates, dumortierite, nigerite)
- Kutná Hora (accommodation) arrival about 7 pm, about 120 km by bus

Tuesday, August 31, 2010 (Day 4)

- Kutná Hora, departure 9 am
- Vlastějovice (Field stop 6: Contaminated pegmatites cutting in Fe-skarn)
- Myšenec (Field stop 7: Tourmaline-beryl pegmatite – natural reserve)
- Písek (Museum stop 3: Prácheň museum, mineralogical collection, *medieval city – visit*, accommodation), arrival about 7 pm, about 160 km by bus

Wednesday, September 1, 2010 (Day 5)

- Písek, departure 9 am
- Příbram (Museum stop 4: Příbram Museum, mineralogical collection)
- Praha (Museum stop 5: National Museum, mineralogical collection), arrival to Praha airport about 4-5 pm, about 120 km by bus

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Rosso, K.M., Bodnar, R.J. (1995): Microthermometric and Raman spectroscopic detection limits of CO_2 in fluid inclusions and the Raman spectroscopic characterization of CO_2. Geochimica et Cosmochimica Acta, **59**, 3961-3975.

Szederkényi, T. (1996): Metamorphic formations and their correlation in the Hungarian part of Tisia Megaunit (Tisia Megaunit Terrane). Acta Mineralogica-Petrographica, **37**, 143-160.

Bakker, R.J. (2002): http://www.unileoben.ac.at/~buero62/minpet/Ronald/Programs/Computer.html. Accessed: June 15, 2003.

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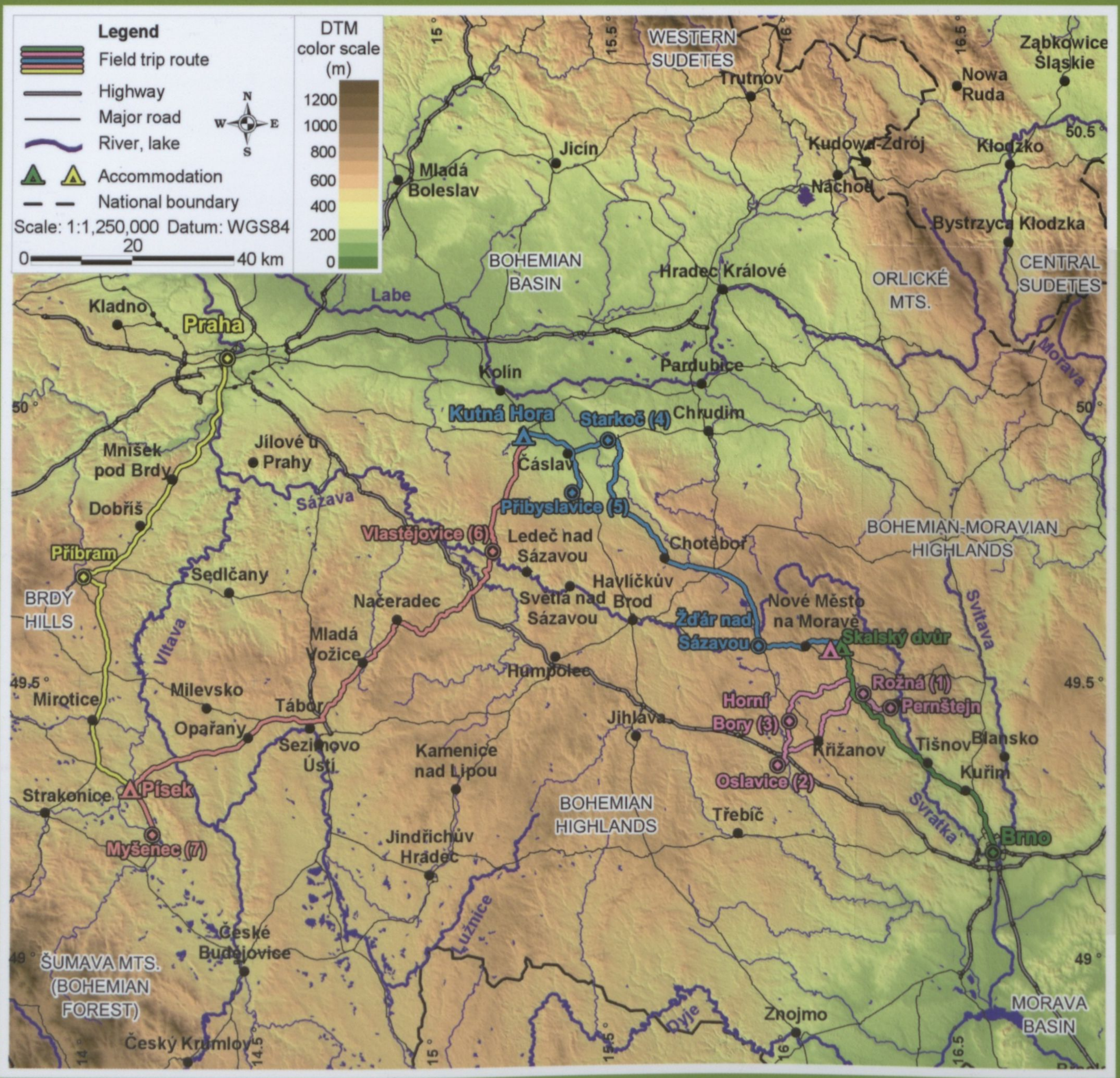

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